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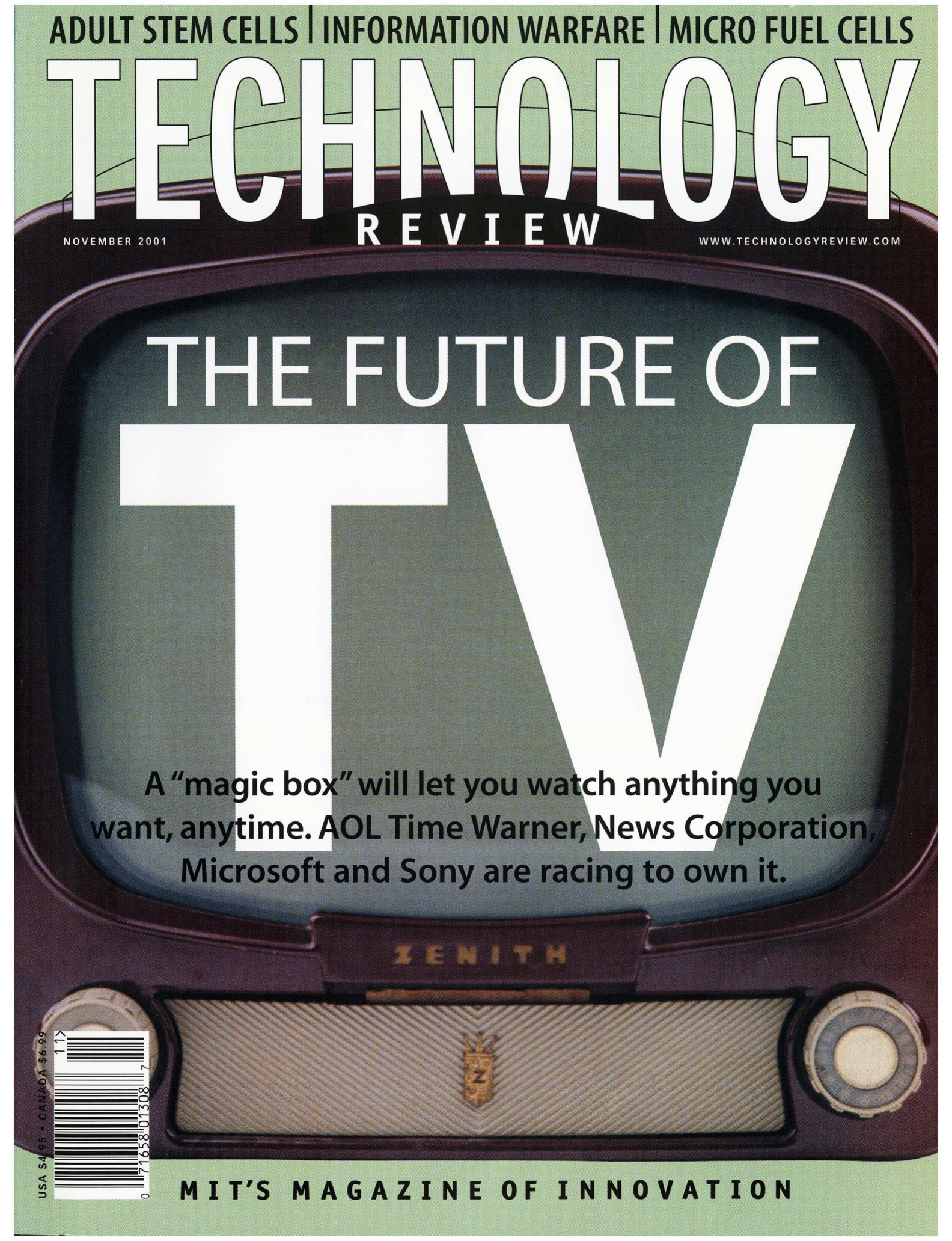

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MIT'S MAGAZINE OF INNOVATION

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THE LEXUS LX 470

Abbreviations seldom do their spelled-out brethren justice. Allow us to elaborate with the aid of the LX 470, one of the world's most capable and luxurious full-time 4-wheel-drive vehicles.

We will begin with AVS, otherwise known as Adaptive Variable Suspension. AVS is actually a sophisticated system that automatically feels the character of the terrain and then adjusts the electronically controlled shock absorbers to respond appropriately.

AVS. AHC. VSC. A REALLY BAD SCRABBLE® HAND OR A REALLY GOOD SUSPENSION?

AHC, short for a quite unique feature called Adjustable Height Control, raises or lowers the body of the LX 470 by almost four inches. Choose the highest setting for the maximum ground clearance while venturing off the road; choose the middle setting in order to help the LX 470

*Lexus Vehicle Skid Control (VSC) is an electronic system designed to help the driver maintain vehicle control under adverse conditions. It is not a substitute for safe driving practices.

achieve optimal handling and fuel-efficient aerodynamics; choose the lowest setting for remarkably easy vehicle entry and exit.

Last on our list is VSC, or Vehicle Skid Control. Working in tune with the LX 470's anti-lock brakes and its four-wheel Traction Control, Vehicle Skid Control helps control loss of lateral traction in a turn by applying one or more of the brakes and, if necessary, reducing the throttle of the LX 470's engine.*

Combine all that with the solid drive of a 4.7-liter V8 engine and enough fine wood and leather trim for up to eight passengers to enjoy simultaneously, and you certainly must agree: Common abbreviations simply fail to do the uncommon ride of the LX 470 justice.

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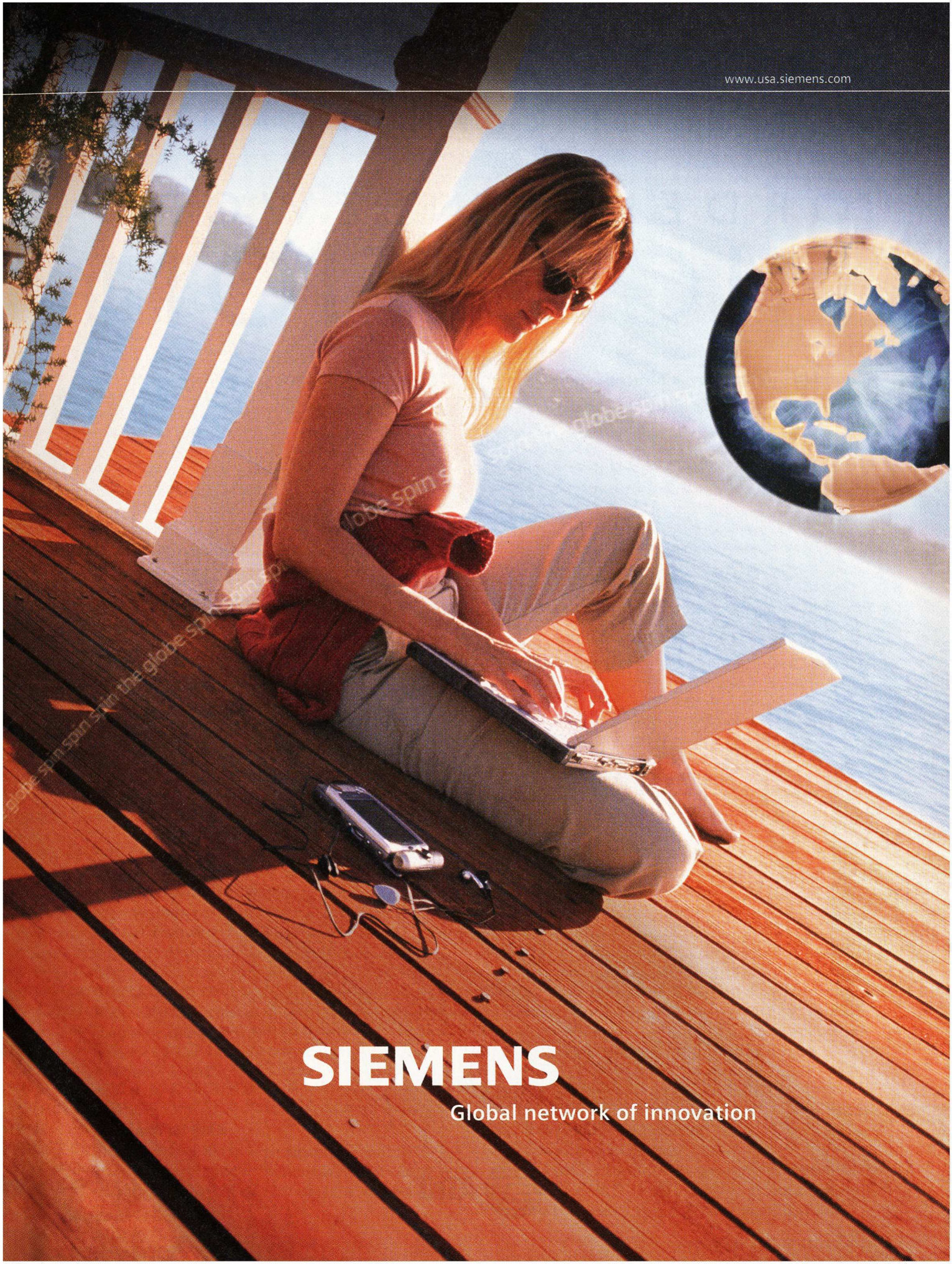
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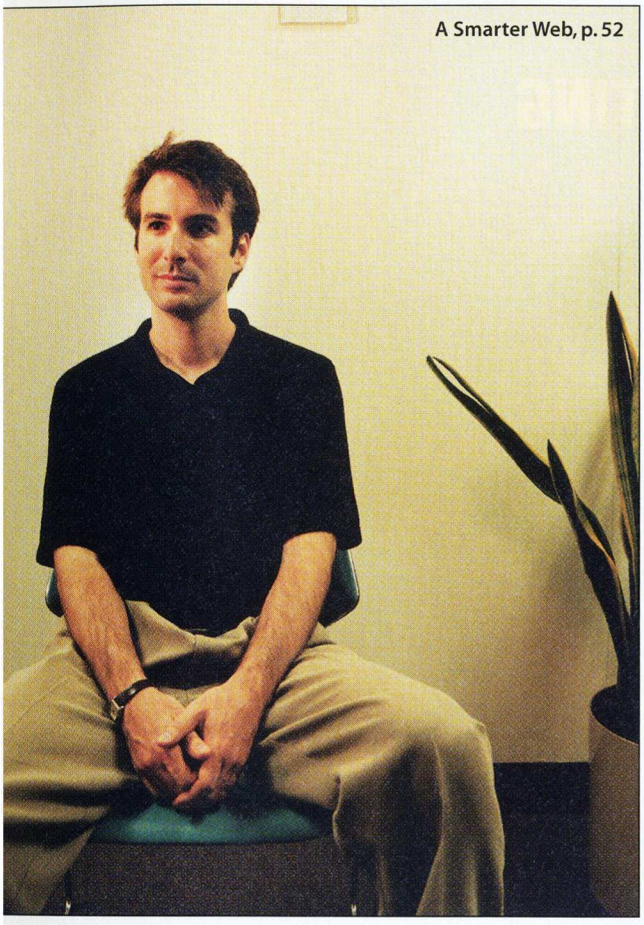

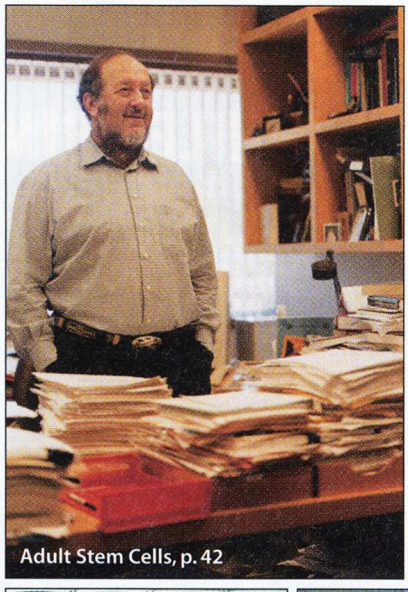

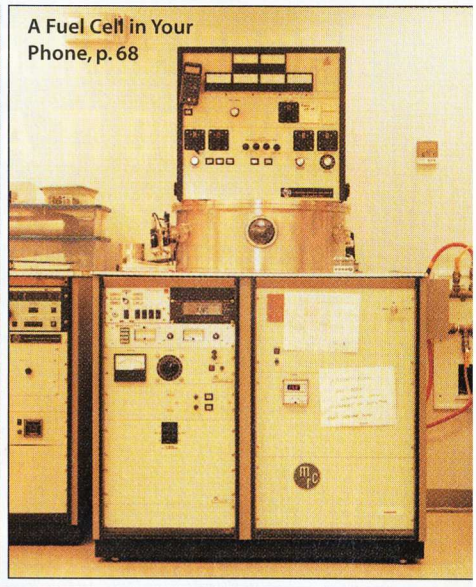

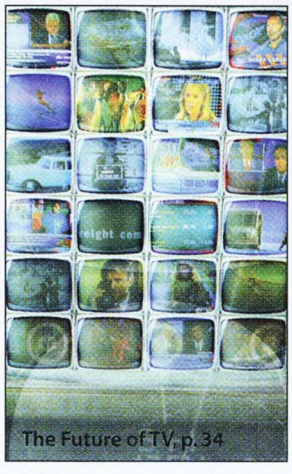

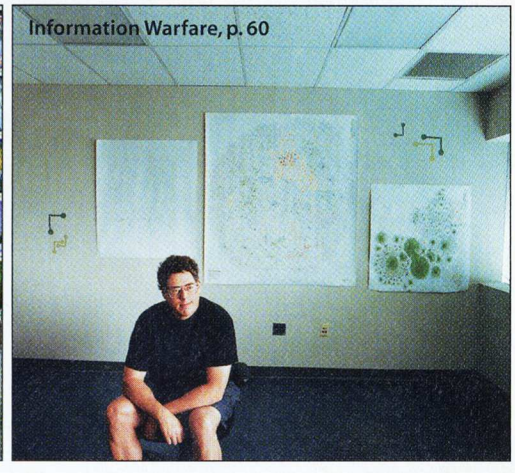

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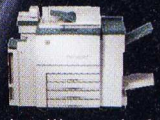

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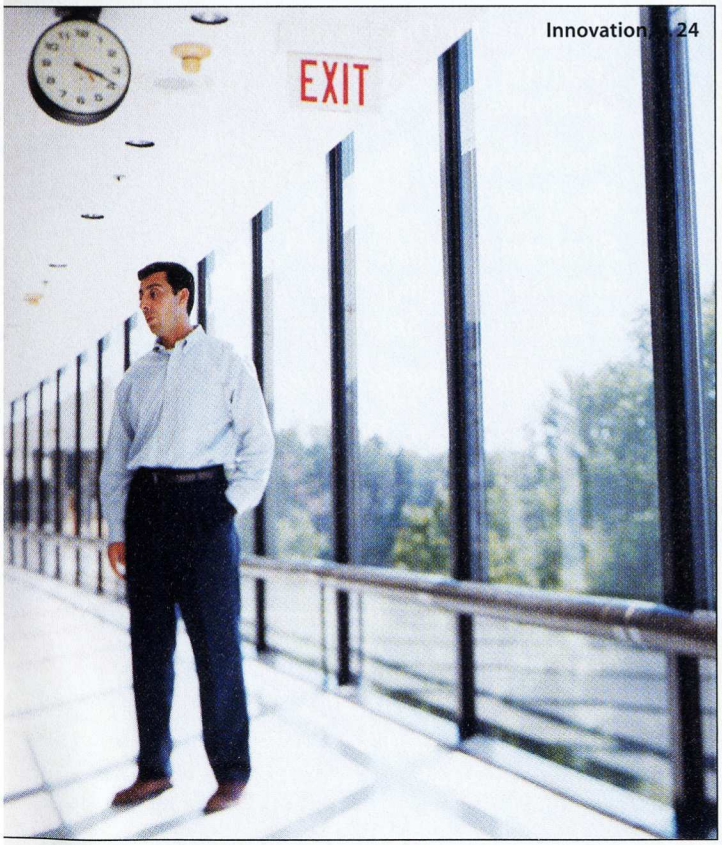

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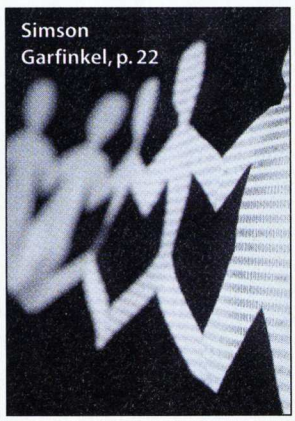
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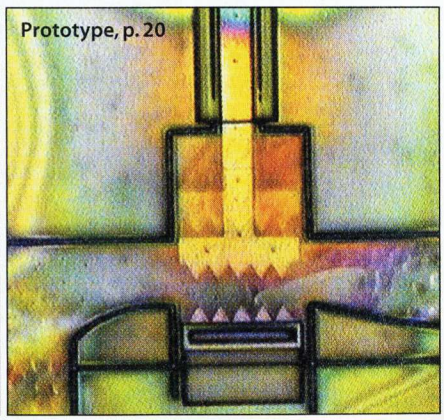
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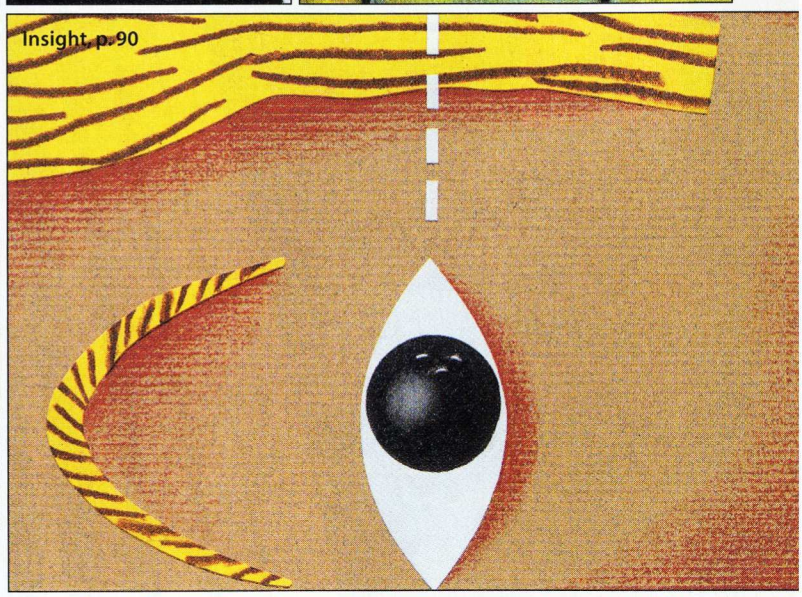
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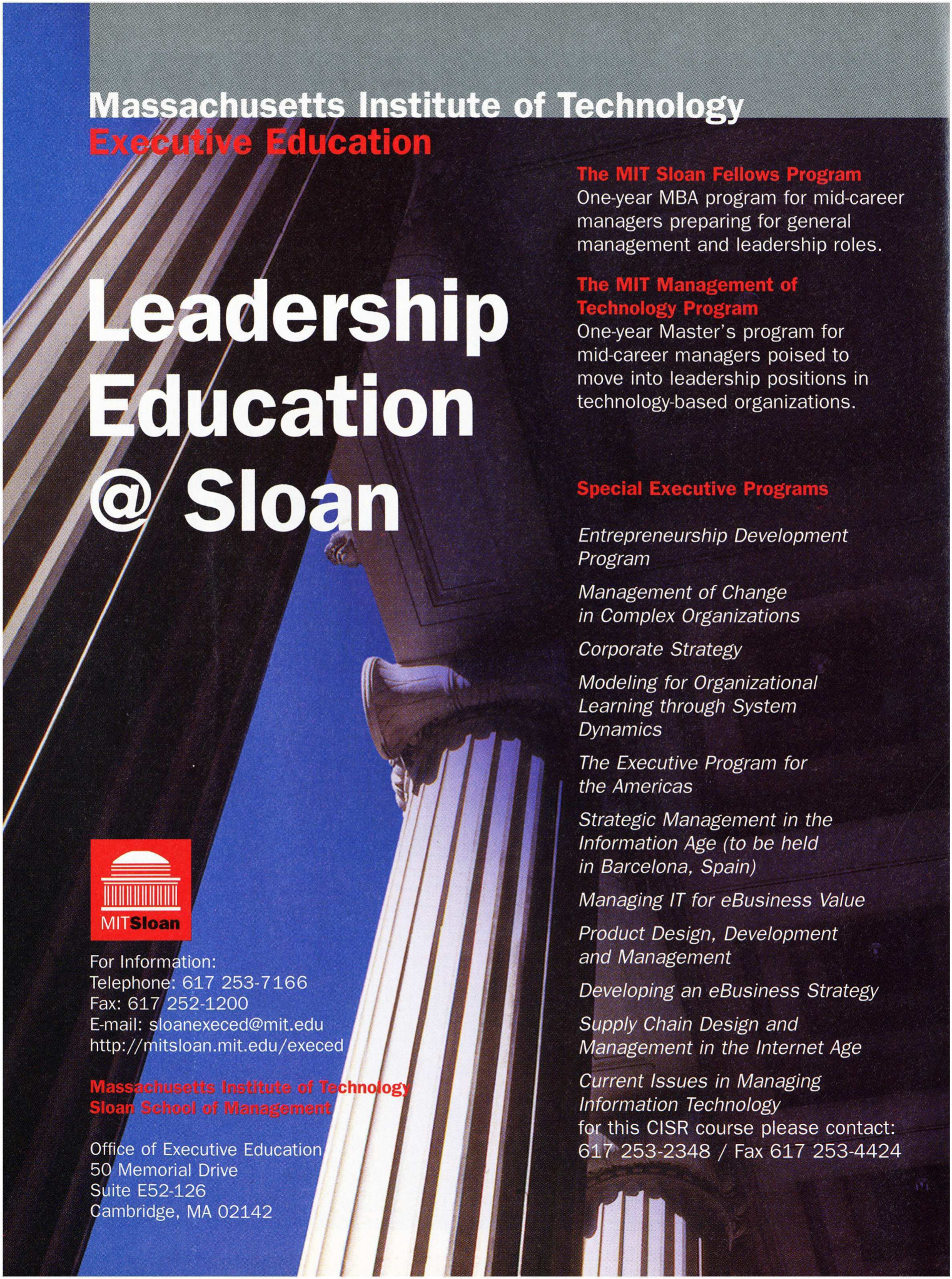
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MIT IN MOURNING

As the sun rose on September 11, we were already in mourning in our new offices at One Main Street in Cambridge. A dear friend and supporter of *Technology Review* had just died, suddenly and shockingly. Michael Dertouzos was the director of the MIT Laboratory for Computer Science and a pioneer in the development of computing technology. The LCS, as it's called around here, was the place where time-sharing was invented, along with the spreadsheet and many other innovations in information technology. Dertouzos was widely mourned in the computing community and the world at large, but his loss was felt particularly keenly in our office, since he had supported the new *Technology Review* from its inception.

Very early in my tenure at this magazine I was introduced to Dertouzos by our publisher and CEO Bruce Journey. Over lunch, I told this imposing outsized Greek what kind of magazine I wanted the new *Technology Review* to be—a magazine devoted to the subject of innovation. He was interested. Since he was a famous innovator, I asked him what subjects such a magazine ought to cover regularly. His eyes lit up and he paused, holding the silence perhaps just a beat longer than strictly necessary, and then answered with a flourish: "The Three Queens!"

The Three Queens turned out to be information technology, biotechnology and nanotechnology. Now, those three choices weren't surprising to me. Information technology and biotechnology were no-brainers, and I had learned a lot about nanotechnology in my previous job at *Science* magazine. Still, having someone of Dertouzos's stature dramatically confirm these choices was a powerful experience. There and then the shape of the new *TR* crystallized.

DONNA COVENEY

Dertouzos

As I got to know Michael better, it became clear to me that the thing that really moved him was the necessity to reconcile new technology and human needs. He was convinced that the fundamental relationship between us and our machines, especially these demanding new machines called computers, was reversed: we were serving them rather than the other way around. They should be our servants, he insisted, an argument that put human beings back in the center of the cosmos—where, according to Greek humanism and Michael's religious beliefs, they had belonged all the time.

So I asked him to write a column on that subject, and since I'd hit on his passion, he agreed. The result, called "The People's Computer," appeared in every issue of our magazine for the first two and a half years after its relaunch in May of 1998. Along the way, I learned that although Michael didn't write for a living, his writing habits were thoroughly professional. His column fit the space available, almost to the word, every time, and it was generally written *before* his deadline. (Ask any editor how common that is.)

Along the way, as Michael Dertouzos moved from supporter of *TR* to columnist, he also became a friend and mentor to me, a source of emotional strength in learning about the MIT community. Therefore it was crushing to hear that Michael had died suddenly. Although he had had medical problems over the summer, he had seemed to be recuperating well, and news of his death was devastating.

Painful as that experience was, it was swept aside by what happened on September 11 in New York and Washington. Like every other community in the nation, MIT was emotionally leveled by the pictures on our television screens. The campus came to a halt as students and teachers turned to each other for comfort. *Technology Review* has assembled a group of stories on the tragedy and its aftermath, drawing on the expertise of the MIT faculty. These stories can be found on our Web site at www.technologyreview.com/aftermath.

COURTESY OF AKAMAI TECHNOLOGIES

Lewin

We have also sustained our own casualties. One of the foremost among them was a brilliant young innovator from the Laboratory for Computer Science that Michael Dertouzos led. Daniel Lewin, chief technology officer of the high-tech company Akamai Technologies, died on American Airlines Flight 11 from Boston to Los Angeles when it hit the World Trade Center's north tower at 8:45 a.m. As a student of LCS professor Tom Leighton, Lewin had developed algorithms that make it possible to manage the profuse and disorderly traffic of the Web.

Lewin was only 31 when he died. His ascent had been so rapid that he did not yet have his doctorate from MIT, even though, along with Leighton, he had already helped found Akamai to commercialize his algorithms. In a sad and painful irony, the very algorithms Lewin devised helped keep many large news sites on the Web from failing on September 11.

It will take a long time to draw out the lessons of these events. But it is already clear that technology was threaded through it all, for better and for worse. As we pick through the devastation, the thing that keeps recurring to me is Michael Dertouzos's insistence on the primacy of humanity, not technology. Our machines exist to serve us and they serve our purposes faithfully. A Boeing 767 can be a remarkably reliable form of transport or a suicide bomb. It is clearer than ever before that what we make of our technology depends on what is in our hearts. —*John Benditt*

Paul Gauguin, Where Do We Come From? What Are We? Where Are We Going?, 1897 Tompkins Collection, Boston Museum of Fine Arts

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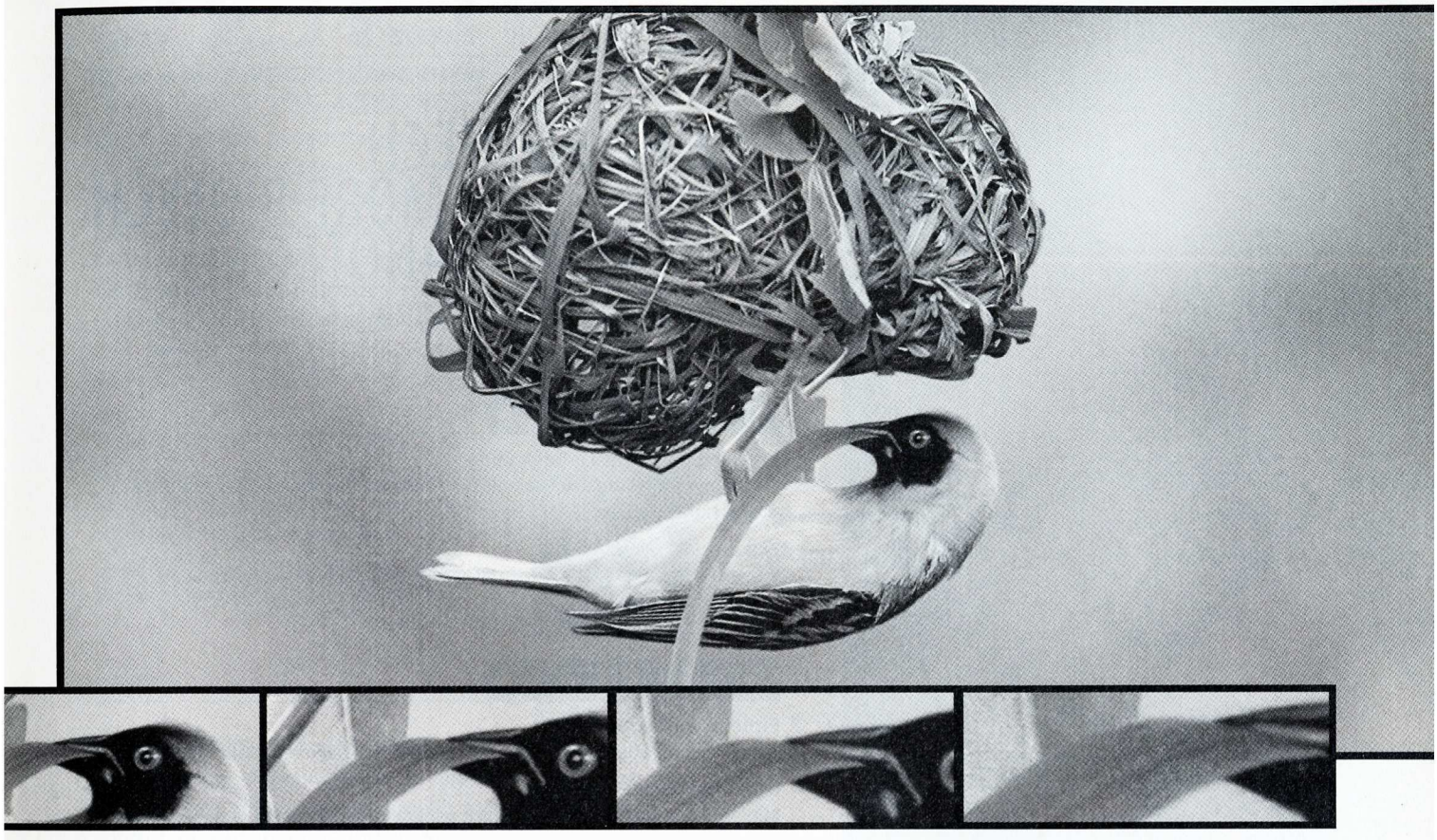

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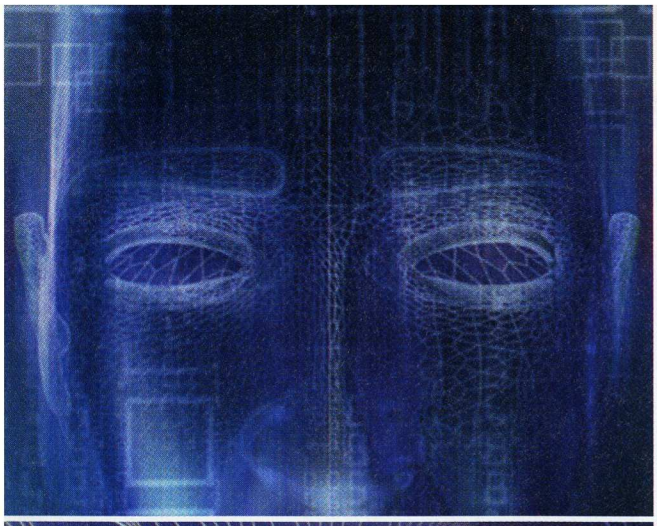

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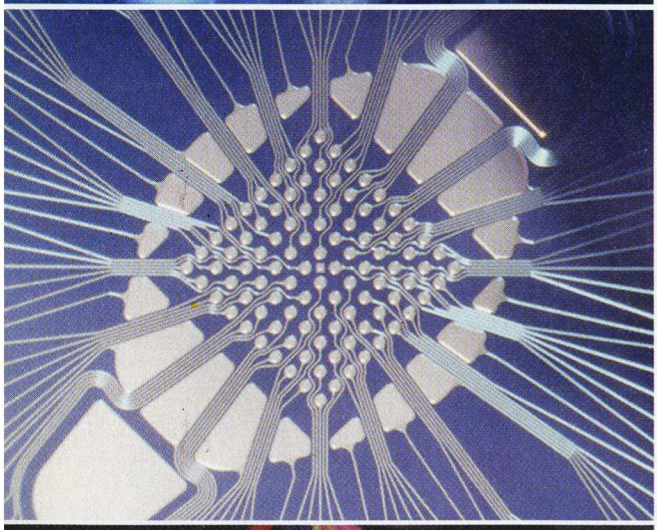

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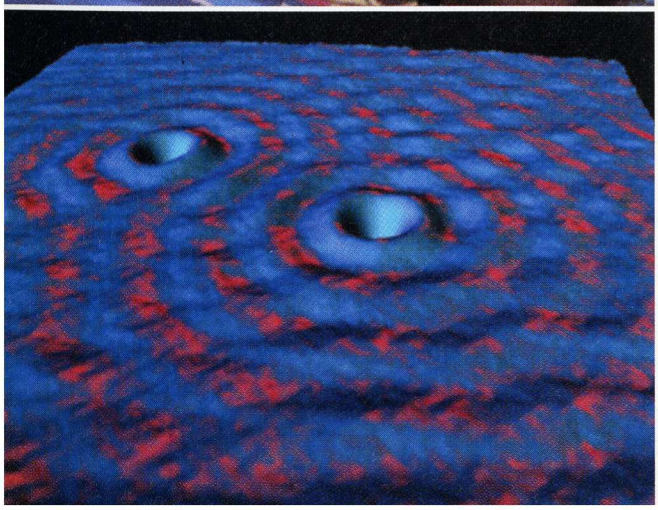

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FEEDBACK

LETTERS FROM OUR READERS

THE WILD WILD WEB

The real truth about the Web ("Taming the Web," *TR* September 2001) is that, if pressured, people can and probably will resort to encrypting all of their information before it goes on the Internet. The National Security Agency and Central Intelligence Agency may or may not have the supercomputing resources capable of breaking the strongest encryption available today, and they certainly don't have the resources to even come close to breaking every single encrypted message, if everyone encrypted nearly everything. Bruce Schneier points out in his book *Secrets and Lies: Digital Security in a Networked World* that we cannot attain complete security, whether through hardware devices or software.

Sam Thomas
Denver, CO

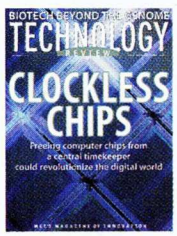
Charles C. Mann's article raises a question: why do the economics of digital content have to be achieved through the control of distribution? Other mechanisms are available. Canada, France and Germany, for example, compensate rights holders for copying by levying taxes on blank cassette tapes and recordable CDs. In Canada and the United States, a percentage of a radio station's gross income is sent to a performing-rights organization—representing songwriters, lyricists and music publishers—along with a playlist that is used to divide up the tariff. Television networks in North America derive their revenue from advertising, with ad rates determined by the estimated size of the viewing audience.

I wonder if these examples aren't a simpler, less expensive way of creating a healthy economic climate for creators and users. No longer would politicians and lawmakers be asked to invade an individual's privacy, fetter the Internet and slow down technological innovation. Instead, the system would be more fair, based on usage, not control of distribution.

Lindsay Moir
Calgary, Alberta

What Charles C. Mann is warning against is the emergence of locks on a society that hasn't used them so far. People who believe that all information on the Internet needs to be free do not want to believe that locks could be effective. True, some people will be able to pick the locks. But locks only need to be good enough to deter a significant proportion of miscreants. It is not an alarming direction to go in. Just as we dislike spammers for stealing our time, we should allow artists the privilege of not having the fruits of their time stolen.

Mukesh Prasad
Enfield, CT



"The National Security Agency and Central Intelligence Agency may not have the supercomputing resources capable of breaking the strongest encryption today."

As the core developer for the software used by the Swaptor file-sharing service that Charles C. Mann discusses (Swaptor licenses the software from us), I would like to correct some incorrect statements in his article. Contrary to Mann's assertion, Swaptor does not index files on a central server. The server that Swaptor operates is only for keeping track of the number of users, files and gigabytes on the network, as well as for keeping a list of the host computers a client can connect to in order to become part of the network. In light of what has happened to Napster, we think it would be a very bad idea to index the files themselves on a central server.

Steve Wiseman
CEO, FileNavigator
Sterling Heights, MI

Charles C. Mann responds:
My account of the Swaptor software was based on a description provided by the company. If that was in error, I welcome the correction. The error does not alter the essential point: the basic functions of this "offshore" site are easily within the reach of U.S. legal mechanisms.

CONTACT US

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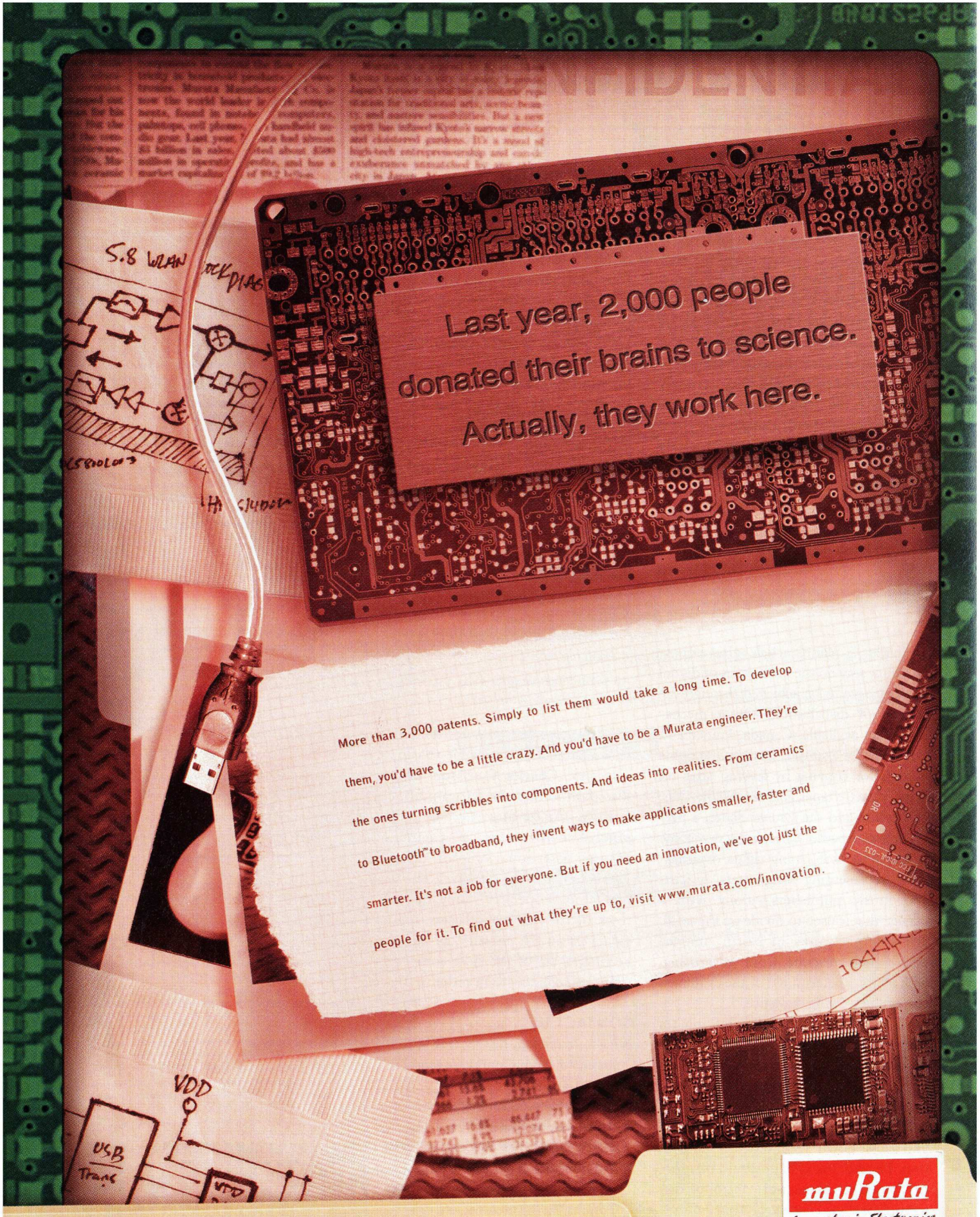
- **To participate in our online forums, visit www.technologyreview.com and click on "Forums," in the menu at left.**
- **Letters may be edited for clarity and length.**

EDUCATING THE SCIENCES

While most of what David Goodstein says about our educational system is unfortunately true ("Science Education Paradox," *TR* September 2001), I have to take issue with his assertion that "the problem starts in grade school." There is no question that many lower-school teachers will often say they are not comfortable teaching science because they have no scientific training or background. I taught chemistry and physics in a prestigious K-12 private school for 26 years and have heard these proclamations firsthand. But I wish I had a dollar for every parent who told me they "hated math and science," or "couldn't understand math and science," or "nearly failed math and science." Remember, education begins long before a child ever gets to school. A parent who expresses negativity about math or science in front of a child is planting the seeds for a math-science-phobic child.

John Ross
Morrisville, PA



Isn't it the faculties of universities and colleges that train teachers? I'd suggest that any scientists who are unhappy with the quality of science education pressure their respective faculties to raise the entrance requirements for teacher education programs and get involved in teacher education.

Vic Tyrer
Oshawa, Ontario

David Goodstein presumptuously measures scientific knowledge in terms of college degrees. Many people who don't have the financial resources feel they can't afford to major in a field like physics. Instead, they read about current research on their own time. I would suggest measuring America's knowledge of and interest in science by the domestic sales volume of science-related books. You will gain a better understanding of specific categories of interest and different knowledge levels through this than by simply measuring degree status. *Technology Review* magazine wouldn't sell so well if Americans were totally apathetic about science and technology.

Tim Ventura
Kirkland, WA

I agree that our country is doing a poor job of teaching science to the masses; however, I would add another reason that should not be discounted. Around 1970 we stopped teaching grammar properly in this country. A student who does not understand the structure of his own language is not able to express the ideas and subtle distinctions necessary for success in science and math.

Patricia Callaway
Gainesville, FL

OBVIOUS ENOUGH?

In Seth Shulman's column "The Greenback Revolution" (*TR* September 2001), he mentions that the pending patent on *Agrobacterium tumefaciens* has been tied up by "interference" since 1983 as four research teams have competed for credit. I understand that to merit a patent, a technology must be "non-obvious." Given that each team was able to make a strong enough claim to this invention that it has taken 18 years to sort it out, how can this technique possibly satisfy the "non-obvious" criterion?

Stephen Rogers
Austin, TX

Seth Shulman responds:
You make a good point. The obviousness criterion is one of the trickiest and most malleable in patent law. According to the mandate from Congress, nothing should be patented that would be obvious to an average "practitioner in the art." But when a field is new—such as the Internet—the patent office often gives the obviousness requirement a narrow, legalistic interpretation that seems to defy common sense. Take, for example, the office's willingness to grant Amazon.com a patent on "one-click technology" that allows shoppers to buy things with one click of the mouse, or its decision to award the firm Open Market a patent on the online "shopping cart." From a nonlegalistic standpoint, both of these inventions appear to be blindingly obvious.

In the case I wrote about in my column, there is no question that an important development in transgenic plant research occurred in the early 1980s when scientists began to use *Agrobacterium tumefaciens* to insert genes into plants. As with so many technological milestones, it was an idea whose time had come, and many researchers in the rarefied field began to recognize its possibility at about the same time. Still, given the patent office's narrow interpretation of the "obviousness" criterion, legally speaking it would be a stretch to argue that the use of this particular germ to transfer genes was so common in the field at the time as to be obvious to the average practitioner. Rather, the interference battle I referred to has been trying to sort out who can rightfully claim to have been first so that they can surmount the patent office's requirement that the invention be "novel."

FIRST EXPLORERS

Biologist Leroy Hood ("Under Technology's Hood," *TR* September 2001) claims that "the genome introduced to biology a completely new approach, which I've since come to call 'discovery science.' It's the idea that you take an object and you define all of its elements and you create a database of information quite independent of the more conventional hypothesis-driven view." This is not at all a new approach to science. Exploratory science has long been a part of biology, as well as astronomy, geology, oceanography and other fields. Some seem to believe that if an activity is not driven by a falsifiable hypothesis, it isn't science. Thankfully, Hood has learned better. Exploration for science has a long tradition.

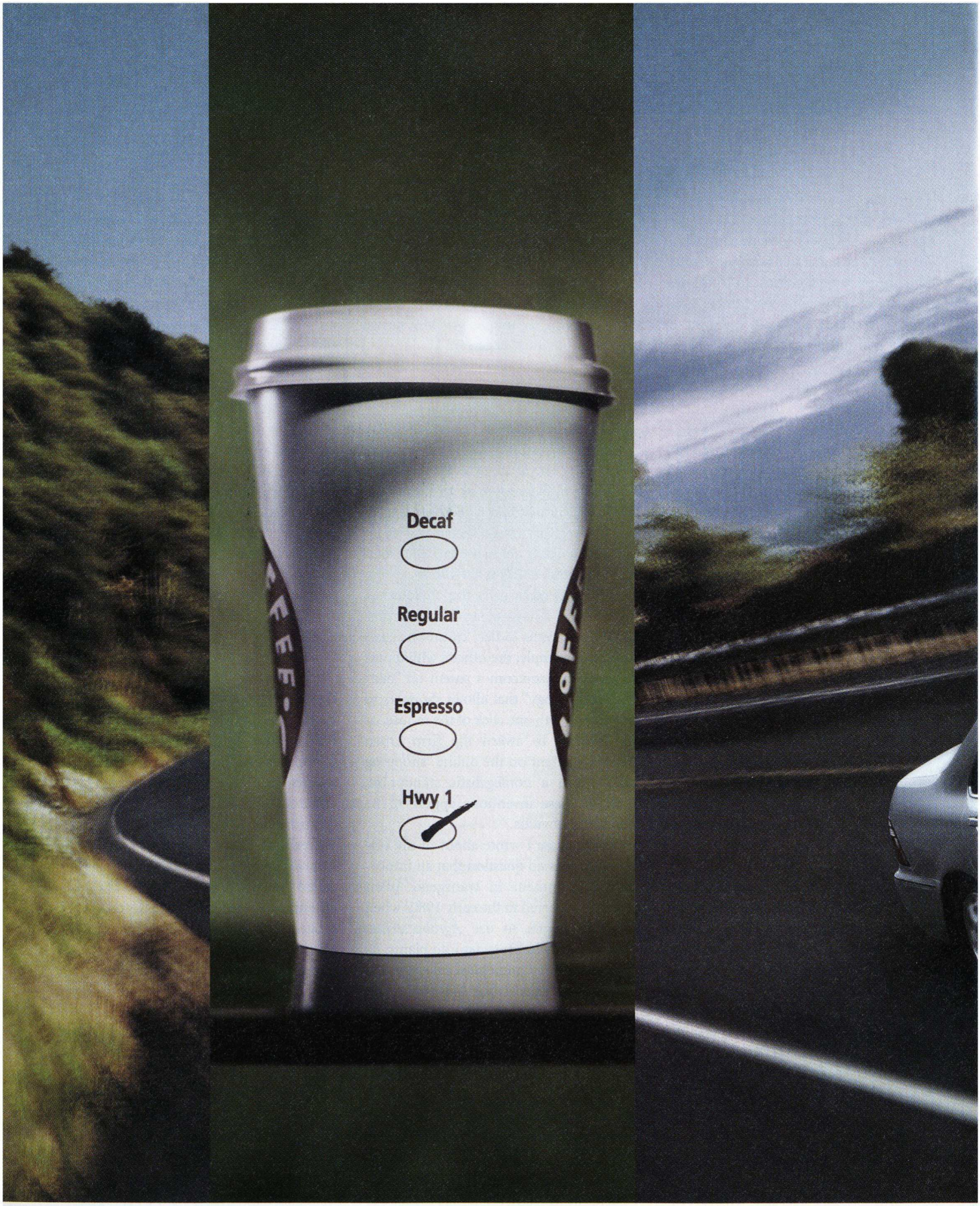
Mark David Handel
Washington, DC

Q&A WITH MICHAEL DELL

Michael Dell is wrong—and boastful to boot—when he claims that Dell Computer was "the first to integrate wireless into notebooks, with integrated antennas" ("Direct from Dell," *TR* July/August 2001). As an owner of an Apple PowerBook G3 purchased in May 2000, I have been using the wireless card called AirPort, along with the built-in antennas of the laptop itself, for much longer than Dell's company has been putting out models with some of the same capabilities. Dell is giving his team credit for something they didn't do, and came late to the party for anyway.

Todd Cunningham
Minneapolis, MN

Technology Review *received many letters similar to Mr. Cunningham's, as did Dell Computer. The company responds:*
Michael Dell's comment on integrated wireless technology in notebooks was made in the context of PC notebooks—that is, those that are based on Intel microprocessors and running the Windows operating system. He meant no disrespect to Apple Computer.



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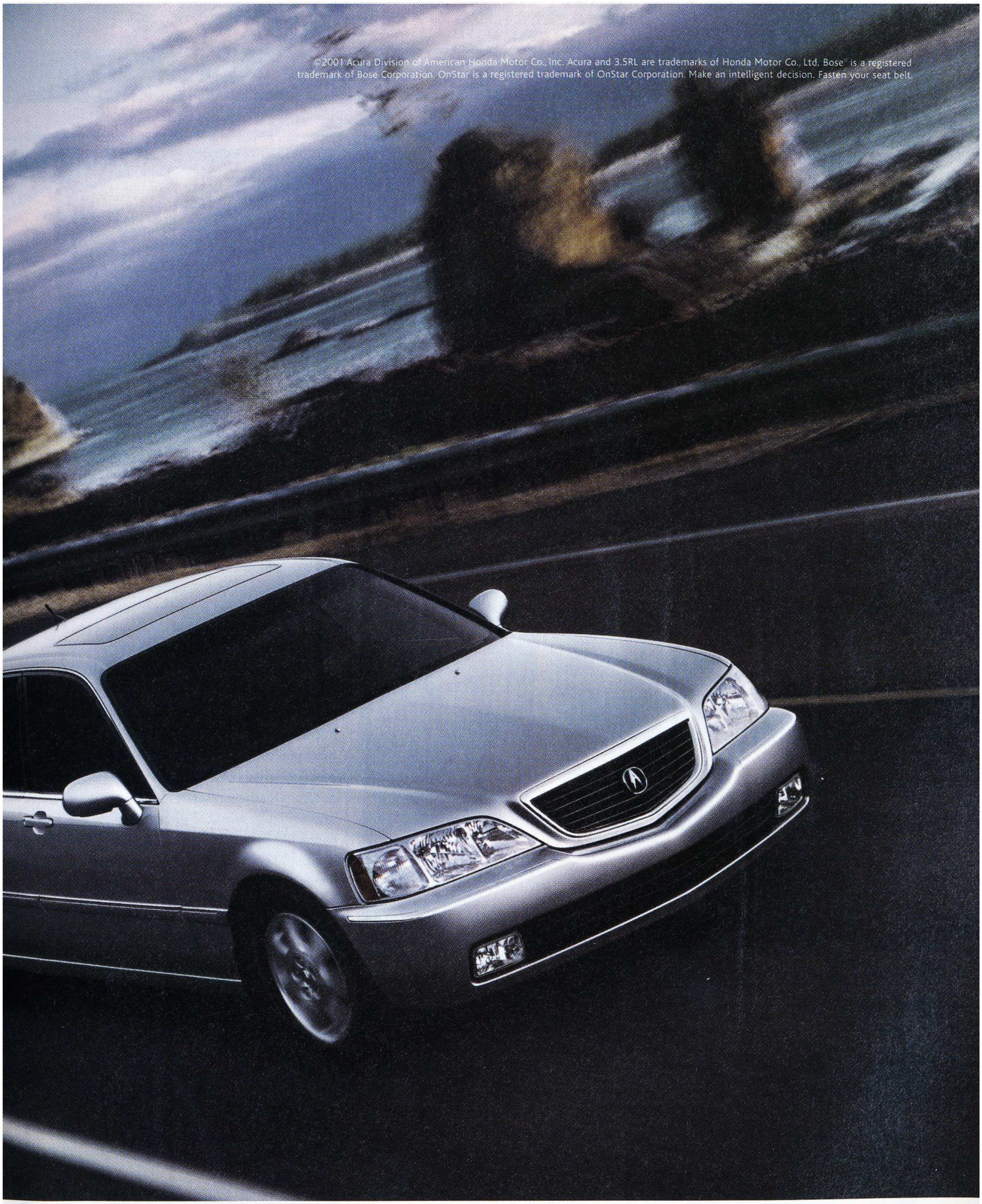

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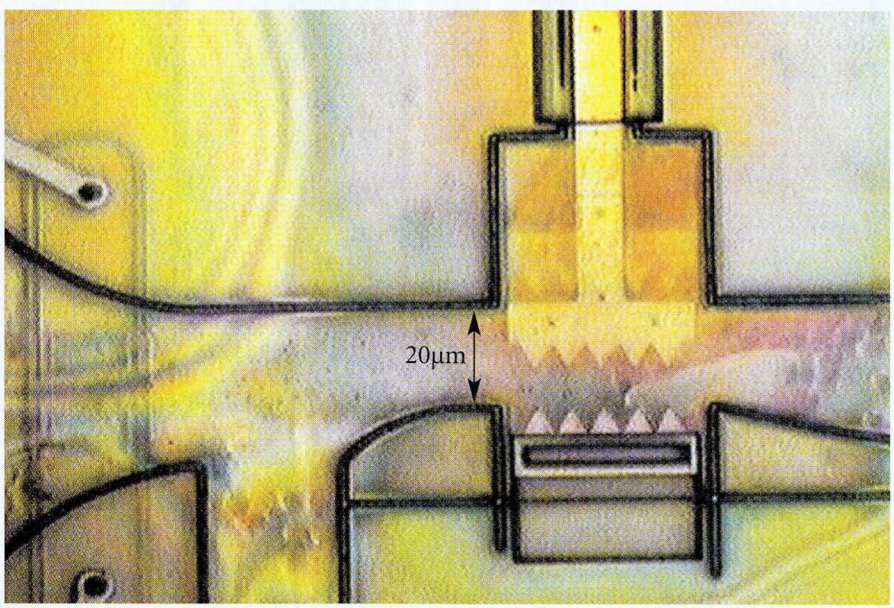
TALK TO THE HAND

Clicking through multiple layers of menus and scrolling through tiny pages isn't the most efficient way to work with electronic information—just ask someone squinting at the screen of a personal digital assistant. Liam Comerford and his colleagues at IBM's Watson Research Center in Yorktown Heights, NY, have developed an alternative that allows interaction through conversational voice commands. Called the Personal Speech Assistant, this handheld goes above and beyond the voice-activated menu commands available with other devices. It understands natural-language queries such as "Show me my address book," or "When's my next appointment?" The assistant extracts the pertinent information from its database and answers with synthetic speech. It also tailors its responses based on the user's needs; if someone forwards through the detailed spoken instructions, for example, the device automatically starts to deliver shorter prompts. As an added bonus, the prototype translates English phrases into any of five languages. The prototype *(photo)* is a stationary unit that cradles a Palm III, but within a year, the software should be available for handheld-device manufacturers to incorporate into their products. "It's mostly a matter of the right party stepping up and saying, 'Gimme,'" says Comerford.

K.O. FOR TB?

Each year, tuberculosis strikes about nine million people worldwide; about two million die from the persistent infection. The disease is becoming deadlier as more strains of the TB bacterium develop resistance to the drugs used to treat it. And the only vaccine against TB, derived from the TB bacteria that infect cows, is often ineffective: in recent tests, the vaccine protected fewer than half of those immunized.

Immunologist William Jacobs and his coworkers at New York's Albert Einstein College of Medicine may have found a way to fortify our crumbling defenses against TB. Jacobs has created a vaccine based on the TB bacterium that infects humans; by using mutant strains of the bacterium, he has made a vaccine that he describes as safe yet far more effective than ones based on the cow TB bacteria. Jacobs hopes to have the vaccine in clinical trials within a year.

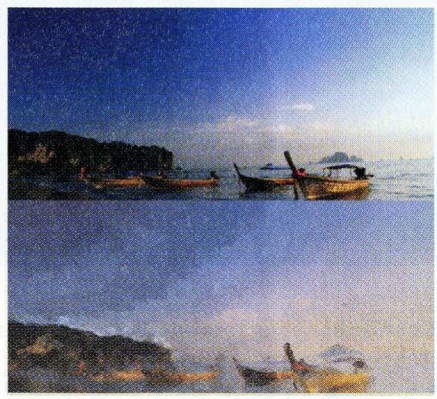


BIOTECH MICROJAWS

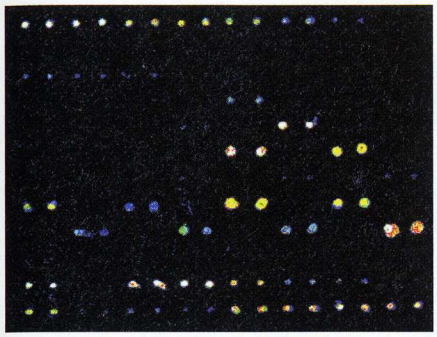
Squeezing all the elements of a biology experiment onto a dime-sized chip promises to speed up everything from the discovery of new drugs to the creation of biotech crops. But fabricating the tiny mechanical parts needed to, say, inject individual cells with genes or drug molecules has not been easy. Engineers at Sandia National Laboratories have created a silicon chip containing microscopic "jaws" with tiny teeth that move back and forth across a chip's microscopic channels *(photo)*. Biologists could use the jaws to gently puncture as many as 10 cells flowing through a channel each second—a dramatic improvement over conventional methods that require manual piercing of cells, one at a time. The Sandia engineers are working on replacing the teeth on the jaws with hollow silicon needles. Needles could simultaneously pierce the cells and deliver a gene conferring a desired trait, for example, or a candidate drug molecule. Sandia engineer Jay Jakubczak hopes to license the technology to biotech firms within a year.

VIRTUAL VIRTUOSITY

Want your computer to paint like a master? A group of researchers from New York University, the University of Washington and Microsoft Research has developed a way for machines to refashion images in particular painting styles—styles learned by analogy, not from mathematical descriptions. The system has been taught to emulate pastel and watercolor texturing effects (as in the processed photo below)—and to make an image look as if van Gogh painted it. A set of "before" and "after" images shows the system how to set up its filter, says Aaron Hertzmann of New York University. Hertzmann says that similar learning-by-example systems might be developed to animate characters based on motion capture data.



NYU MEDIA RESEARCH LAB (BOATS); SANDIA NATIONAL LABORATORIES (MICROJAWS); IBM RESEARCH (HANDHELD)



Glowing dots on a chip indicate a patient's allergies—in this case a variety of grasses.

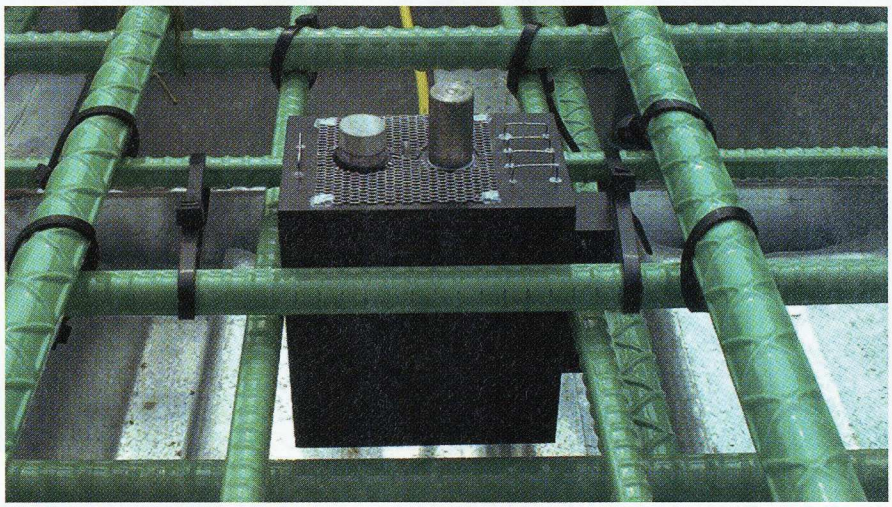
NOTHING TO SNEEZE AT

A new, biochip-based allergy test may soon tell you everything you're allergic to from just a single drop of blood. That's good news for the 50 million or so Americans who suffer from allergies—often without knowing it. Conventional allergy testing requires either injecting suspect allergens under the skin and watching for a reaction or sending a blood sample off for testing. Both methods are painful, cumbersome and costly.

The new test, being developed by New Haven, CT-based Molecular Staging, looks for as many as 100 different allergens at once in a finger prick of blood smeared on a chip. Allergy-causing antibodies in the blood bind to allergens on the chip; the company has a method of amplifying the resulting fluorescence so it can be sensed in a conventional biochip-reading instrument to determine the existence and severity of allergies. The company is in discussions with biochip makers; once an agreement is made, a product should follow within 18 months.

CONSERVATION COOKING

Electric ovens are not generally known for energy conservation. Researchers at England's Cranfield University have built one that consumes 35 to 60 percent less electricity than those now available. Mechanical engineers Marcus Newborough and Bryan Shaughnessy lined the walls of the oven with a heat-reflecting aluminum alloy *(photo)*. "About 93 percent of the radiation striking the chamber's lining is directed back at the food being heated," says Newborough. A second reflective lining between the cooking chamber and its outer insulation further prevents heat from escaping. The researchers are seeking partners to license the technology, which they expect to reach the market in about two years.



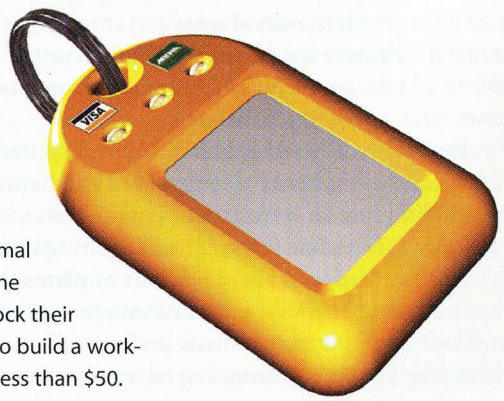
RUST REPORTER

Crumbling bridges often get that way because steel reinforcement bars have rusted within the concrete. A Charlottesville, VA-based company called Virginia Technologies has devised a system of networked sensors that can be embedded in concrete, tell when the steel is corroding and report the information through a wireless link—avoiding the need to drill holes or install probes that must be checked individually.

The networked probes are tethered to the steel bars and wired together before concrete is poured *(photo)*. Each sensor monitors electrochemical factors that indicate rusting, such as changes in salinity, moisture and conductivity. If any one instrument detects a relatively high corrosion rate, it can check with neighboring sensors to gauge how far the problem has spread. Sensor readings travel by wire to a communications module, from which the data can be accessed wirelessly. The company expects to bring the sensors to market early next year.

MAGIC FINGERS

A device the size of a car-alarm remote could one day unlock cars and homes as well as validate credit card purchases and bank transactions—all by reading the user's fingerprint and wirelessly transmitting it to a third party for authentication. The tiny gizmo *(photo)* is the brainchild of Palm Beach Gardens, FL-based Cross Match Technologies, which specializes in fingerprint capture devices. The device will also sense blood flow patterns in the finger. This will add an extra layer of security to the device; not only must the finger be attached to a living person, but if the blood is flowing faster than normal (say, if the person attached to the finger is being held at gunpoint), the sensor can void the transaction. The sensitivity can be set for different applications, so runners could still unlock their doors after a jog but might have to wait 20 minutes to use the ATM. Cross Match hopes to build a working model in the next two and a half years. The company's target is a product selling for less than $50.



CROSS MATCH TECHNOLOGIES (FINGERPRINTER); MARCUS NEWBOROUGH (OVEN); VIRGINIA TECHNOLOGIES (BRIDGE); MOLECULAR STAGING (CHIP)

STEPHEN SHEFFIELD

SUPER SYNC

For decades, future-gazing technologists and visionaries have assumed that technology would bring into being some sort of electronic Library of Alexandria. In this scenario, massive databanks would be centralized information utilities, with access granted by cheap, fast and ubiquitous data feeds. In *Star Trek,* for instance, crew members used a wireless network to link their tricorders with the starship *Enterprise*'s onboard computer—that storehouse of all things interesting and relevant. And the original Internet was created not to distribute information, but as a massive remote-access system, enabling researchers in one place to tap into computers located somewhere else. Even George Orwell's *1984* envisioned a world in which records of news and current events were stored in relatively few places; that's how Winston Smith was able to edit the past so that Big Brother's pronouncements were never wrong.

But reality is heading in a different direction. Instead of ubiquitous connectivity to centralized databanks, we are instead building an infrastructure that's optimized for data *replication.* The same information is getting copied to dozens, hundreds or even thousands of places throughout the world, and it is kept current through continual retransmissions and updates. Humans instinctively work this way—that's why people collaborating on a project tend to exchange documents by e-mail rather than putting them on a central server. After all, sometimes we are connected to one of these data repositories on a fast network, sometimes we are connected on a slow network, and sometimes we aren't connected at all. People like having their own copies, and then keeping them up to the minute by invoking an incredibly powerful concept called "sync."

Sync—short for synchronization—is all about being able to take data from one location and intelligently copy it to wherever it might be needed. And most importantly, sync is about tracking changes. A good sync system allows you or others to freely edit either the original document or the copies, and then have your changes automatically propagate wherever they are needed. The best of these systems track changes as they are made and allow for sophisticated "undo"—for example, restoring the data to the way it was on a particular date, or removing all of the changes made by a particular author. Sync is not a new idea, but it has only recently begun to emerge as a crucial part of the way that computer systems are run. Sync technology really will set the tone for future computing.

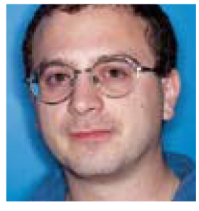
Today the leading sync platform is the Palm operating system, which I've lauded in the past. In fact, one of the big reasons for the Palm's popularity is its "HotSync" technology. Palm users can add, delete or change their address books, appointment calendars or other databases on either their desktops or their Palm-based computers. Put the Palm into its cradle and press the "HotSync" button, and the changes are automatically replicated on the other machine.

But HotSync doesn't stop there. You can, for example, sync multiple desktop computers to the same Palm, allowing people at both your home and your work to access and update your calendar—even if there is no network connection between them. All you do is carry the Palm back and forth between home and office, synching at both locations; the intelligent software does the rest. If you forget to sync, it's no problem—the next time, the system automatically adjusts.

Of course, sync technology goes way beyond the Palm—and way beyond one person's desktop PC. A synchronization program called the Concurrent Versions System is at the root of many successful software development projects, from

small corporations where a few programmers are working on the same project to large-scale open-source collaborative efforts enrolling hundreds or thousands of programmers. This technology makes it possible for many people to work on the same program at the same time. Every programmer has a personal copy of the software being developed. A programmer who adds a new feature or fixes a bug can "commit" that change to the project's repository. Other programmers—either down the hall or across the globe—can then update their copies and automatically have the changes applied. It used to be cumbersome for more than one person to work on a single program at the same time. But now, simultaneous development and bug-fixing are the rule rather than the exception. The Concurrent Versions System, built on the concept of sync, has dramatically sped up software development.

For open-source programmers seeking to compete with commercial software, sync has been a curse as well as a blessing. It is tremendously difficult to design applications that get sync right. The advanced synchronization systems built into commercial database software like Oracle make it possible to build huge database farms by linking together large numbers of synchronized servers. So far, leading open-source databases like PostgreSQL and MySQL provide only limited support for database synchronization. The open-source systems will probably catch up one day soon, but the technology is inherently difficult to develop.



Sometimes the information source being synched is a moving target. Consider Usenet, the original global bulletin board system. When two Usenet servers connect, they essentially synchronize their articles. If an article is on one machine but not the other, a copy is made to eliminate the discrepancy. Back in 1991, John Gilmore, one of the founders of the Electronic Frontier Foundation, said, "Usenet interprets censorship as damage and routes around it." What he meant was this: any university or business that doesn't like articles posted on Usenet may delete them from its server, but because the articles flow through the network as a whole, no one institution can block information from getting out to the world.

In recent years, Gilmore's quotation has been reinterpreted by many journalists as referring to the Internet rather than Usenet. Sadly for both Gilmore and the cause of free speech, this alteration makes the quote inaccurate. When articles are published from a Web site, instead of through Usenet, they are indeed distributed from a central location—and that central location can be subject to censorship or other forms of political pressure.

Online file-swapping operations like Napster and Gnutella are really just very large synchronization services. Users have their own visions of what music or other files they want, and they sync and sync until they are happy. Here, "sync" applies not to an individual file but to a collection. The results, however, are much the same.

Downloading music from a file-sharing service is fundamentally different from downloading information over the Web. In the case of the Web, very few readers keep and redistribute their own long-term copies. This is why Napster and its descendants are threatening to the music industry; as Usenet showed, it can be exceedingly difficult to stop the spread of data through a large-scale synchronization system. Indeed, one of the great advantages of sync is redundancy: even if the "master" copy gets erased, sync invariably leaves many other copies around. This phenomenon makes it hard for outsiders to eradicate or control information that is shared by sync.

Understanding the uses and power of sync is vital for accurately predicting the direction that the Internet and e-commerce are likely to grow. Most people like the safety that comes from having data in multiple locations, and the speed that comes from having the data immediately available on their own computers. Products and services that offer sync, therefore, will probably fare better in the marketplace than similarly priced services that offer high-speed access to data stored on remote systems. People don't want to just tap into a data stream; they want to have their own copy of the information, and they want it kept up-to-date. This has broad implications for everything from video on demand to home banking. I've been doing so-called Internet banking with Intuit's Quicken software for years: every few days, I download my account's most recent transactions and corrections over the Internet and add them to my register. My bank also lets me view my whole statement on the Internet. Would I give up downloading the transactions by themselves? Not on your life—I feel safer keeping my own copy.

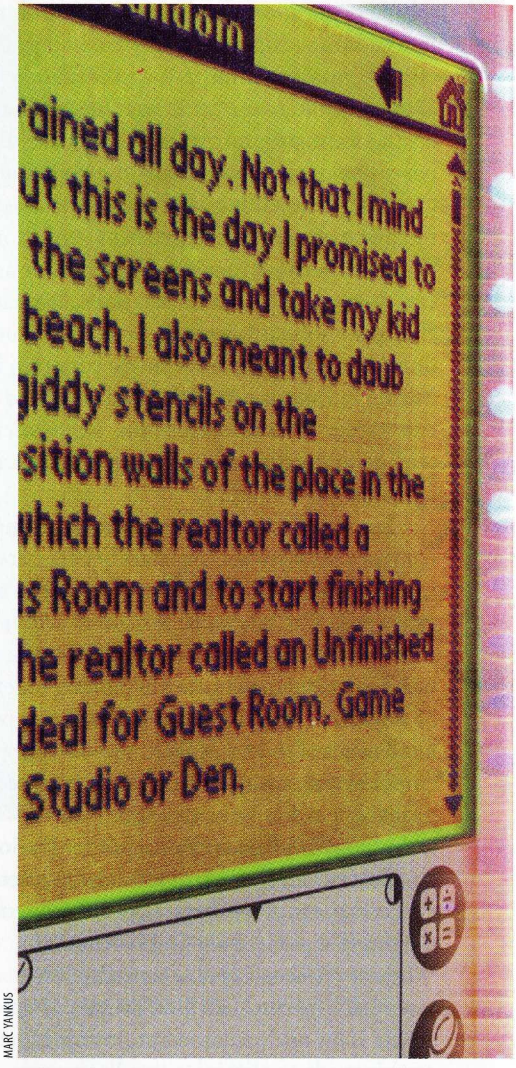
Instead of ubiquitous connectivity to central databanks, we are building an infrastructure of data replication: the same information is copied to multiple locations and kept constantly up-to-date.

Sync makes economic sense too. With sync, you aren't so dependent on an expensive, always-on, high-speed Net connection. You can get much of the same effect with local storage and slow or even intermittent network connections. Sync really does mirror the way that the world has been built—as opposed to the way that pundits and engineers thought it would be.

In fact, even the Library of Alexandria was built through sync. Every ship that docked in Alexandria was searched for scrolls: if any were found, the ship was not allowed to leave until the scrolls were copied. Alas, the library's hundreds of thousands of scrolls were lost when they were burned by Julius Caesar in 47 BCE because they didn't sync a backup.

BREAKING MICROSOFT'S E-BOOK CODE

An anonymous programmer has found a way to decrypt Microsoft Reader e-books, spurring digital-rights debate.



MARC YANKUS

It's easy to load a small library of electronic books into your laptop or handheld organizer and take it on the bus or to the beach. But try to make backup copies of those e-books or loan one to a friend, and you'll run smack into the digital equivalent of an electrified fence. The problem is that once a literary work has been liberated from the printed page, it's potentially vulnerable to unlimited digital piracy—a danger that makes most e-book publishers insist on strict software controls to prevent anyone but the purchaser from opening an e-book file.

Competing "digital rights management" systems offered by companies such as Adobe Systems, Microsoft, Reciprocal and ContentGuard allow publishers to outfit e-books and other forms of electronic content with customized usage rules. The companies naturally strive to make these systems as hacker-proof as possible. But this summer *Technology Review* learned of a home-brewed decryption program that defeats the most advanced antipiracy features built into Microsoft Reader, a leading e-book program downloaded by over a million people since its debut in August 2000.

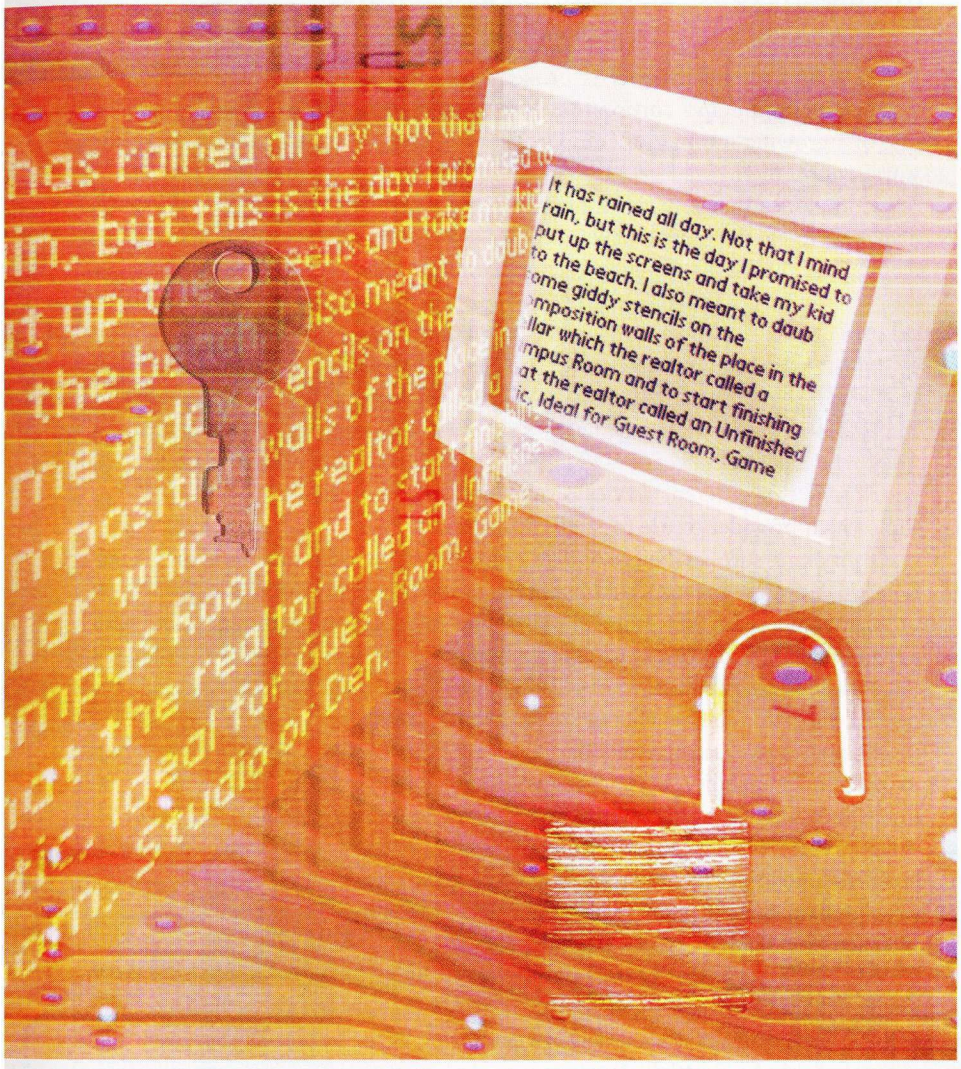
The decryption program lets purchasers of "owner-exclusive" Reader titles—Microsoft's most protected e-book—convert the titles to unencrypted files viewable on any Web browser. The program's creator, a U.S. cryptography expert who asked not to be identified, says he wanted to circumvent the "two-persona" limit, a rule built into Reader at the behest of publishers that allows purchasers to read each e-book on no more than two devices. (In October Microsoft announced it would increase that limit to four devices, as part of a software upgrade planned before the cracking episode.)

Though the decryption program works on any Windows PC, the programmer hasn't released it, saying he developed it for his personal use. But the program's existence, together with decryption efforts directed against e-book formats from other companies, such as Adobe, illustrates the vulnerabilities in digital rights management schemes. It also promises to fuel the ongoing debate over the 1998 Digital Millennium Copyright Act, under which it is legal in certain circumstances to use—but, paradoxically, not to make or distribute—software that circumvents technological copyright protections.

Microsoft controls access to copyright-protected e-books through Reader, a free program that can be installed on any Windows laptop or PC. When you purchase a Reader e-book from a retailer such as Amazon.com, special server software equips your title with one of three levels of copy protection, as specified by the publisher. E-books with owner-exclusive protection, the level used for premium titles such as current bestsellers, are encrypted during download using a unique mathematical key contained in your copy of the Reader software. You obtain this key by "activating" your copy of Reader, which requires you to register for a Microsoft Passport account and supply Microsoft with an e-mail address and other identifying information. Until October, only two copies of Reader could be activated under the same Passport account—now four copies can be activated—and access to owner-exclusive e-books is limited to the devices on which those copies of the software are installed.

Such rules irritate many e-book readers, who feel that once they've purchased a book, they should be able to read it wherever they want. "I like to read e-books at my desk, when I'm traveling, lying on the sofa and when I'm eating lunch. I use different computers for these things, so I need more than two activations," said Roger Sperberg, publishing consultant and columnist for the industry site eBookWeb.org, in August. Some also complain that Microsoft's limitation makes it difficult to recover e-books after a hardware upgrade, which can invalidate the activation key. The anonymous programmer says he wrote his decryption software partly to sidestep such practical problems, and partly so he could extract the text of his e-books for display on additional devices such as the REB1100, a reading device manufactured by RCA.

The programmer's software works by recovering a series of well-hidden encryption keys specific to each activated copy of Reader and to each owner-exclusive e-book. It essentially reverses the process publishers follow when they assemble source files such as text and images into an e-book. The software dumps unprotected copies of these files into a new



folder on the user's computer—as the programmer demonstrated to *Technology Review* using an owner-exclusive e-book purchased from an online bookstore.

Approached for comment, Jeff Ramos, director of worldwide marketing for Microsoft's "eMerging Technologies" group, said, "We do not comment on alleged security violations of our software. In general, if necessary in response to such incidents, we take appropriate measures."

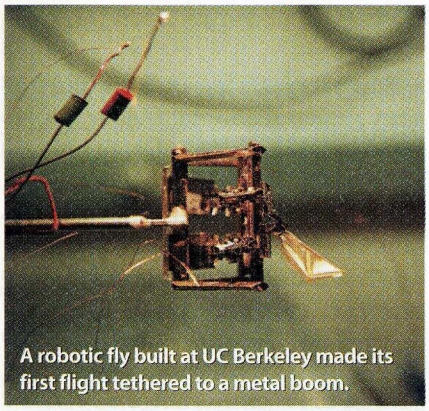
So far, programmers intent on exposing e-book security weaknesses haven't been deterred, even by the possibility of legal action. Indeed, the publicity surrounding the prosecution of Dmitry Sklyarov, a Russian cryptographer who wrote similar software that strips copy protection from Adobe e-book files, has only added to widespread criticism of digital rights management technologies and the laws designed to bolster them. FBI agents arrested Sklyarov at a July hacker convention in Las Vegas after a tip-off from Adobe that Sklyarov's employer, ElcomSoft, had been selling the protection-removing software from its Web site. The arrest—the first criminal case brought under the Digital Millennium Copyright Act—spurred a boycott against Adobe products and protests against the company in more than 20 cities around the world. (Adobe quickly withdrew its support for the prosecution, and Sklyarov was released from custody in August. The U.S. Department of Justice continues to pursue the case.)

One issue in the Adobe debate is a conflict in the copyright act. An exemption to the legislation makes it legal to circumvent technological protections when an e-book is malfunctioning, damaged or obsolete. Civil-liberties groups such as the Electronic Frontier Foundation say such exemptions are necessary to protect traditional rights of "fair use" of copyrighted materials. But the act outlaws the manufacture, distribution or sale of software or devices that would allow consumers to exploit the exemption—a provision supported by publishers. "There is no device that can currently distinguish between a fair use and an illegal use of a copyrighted work," explains Allan Adler, vice president for legal and government affairs at the Association of American Publishers.

But unless publishers give readers the leeway to use e-books the way they use print books, say critics, few will buy into the technology. EBookWeb's Sperberg applauds Microsoft's decision to raise the activation limit, and says getting rid of the "crazy catch-22" in the copyright law would be another good step. The fact that Microsoft has joined Adobe as a victim of e-book decryption efforts, he says, should make it clear that "digital rights management doesn't make things harder for the professional pirate or the black-market publisher; it makes things harder for me, the reader." Until software firms and publishers figure out how to protect e-books without treating all readers like thieves, the summer of beach-blanket e-books may never materialize. —*Wade Roush*

(An earlier version of this story appeared on www.technologyreview.com.)

The decryption software illustrates the vulnerabilities in digital rights management schemes, and promises to fuel the debate over the Digital Millennium Copyright Act.



A robotic fly built at UC Berkeley made its first flight tethered to a metal boom.

TIMOTHY ARCHIBALD

ROBO-FLY

MICROFABRICATION | It was almost Kitty Hawk for the micromachine crowd. Researchers at the University of California, Berkeley, achieved the first limited flight of the smallest-ever flapping-wing machine.

Berkeley's robo-fly has a wingspan of just three centimeters and weighs 300 milligrams—about the size of a rose petal. At that scale, the aerodynamic principles that keep airplanes aloft don't apply, so the researchers modeled the device on a fruit fly, which both flaps and rotates its wings hundreds of times per second. "If it was just flapping, we would have had this a couple of years ago," says project leader Ron Fearing. Actuators made of piezoelectric ceramic materials—which expand and contract when an electric charge is applied—move the robot's polymer wings.

The inaugural flight was just 30 centimeters and used one wing, while the robot was tethered to a metal boom. Albert Pisano, director of Berkeley's Electronics Research Lab, says the project is "paving the way for increased understanding of microscale aerodynamics, microscale mechanical systems and microscale fabrication methods." The U.S. Department of Defense, which funds the project, would like to use tiny flying machines for battlefield spying; eventually, they could act as weather sensors or air duct inspectors.

Fearing says that the robo-fly is not yet ready for untethered flight. He hopes it will be by 2003. "It's not quite Kitty Hawk yet," he acknowledges. Still, 30 centimeters is a lot at the insect scale; after all, the Wright brothers only made it 36 meters on their first flight. —*David Talbot*

DIRECTING TRAFFIC

Intelligent routing lets firms avoid Internet delays

SOFTWARE | "The Internet is broken." So says Ed English, vice president of strategic planning and corporate development for San Jose, CA-based netVmg, one of a growing number of companies out to spot Internet traffic jams and find ways around them.

Companies that rely on the Internet are increasingly using multiple service providers to get the most reliable access possible. The system's not simple, though. Companies must set rules for which of those providers they will use to send different kinds of data; for example, they might send e-mail over the cheapest, but slowest, network, while sending Web traffic out on an expensive but fast connection. The approach often leads to high costs and gives variable results; the expensive provider, for instance, might have an equipment failure or unusually high traffic in the middle of the day. The solution? Intelligent Internet traffic management. Intelligent-routing companies use proprietary techniques to measure the performance of different service providers throughout the day and decide in real time which provider to use for a given piece of data.

By making sure each piece of data heads out in the right direction, says Charles Rutstein, research director at Forrester Research, "these guys are trying to solve the problems underlying the protocol that routes information on the Internet," which aims to ensure that information reaches its destination, without regard for how long it might take to get there. The benefits of solving those problems are improved performance and reliability and, perhaps more importantly, cost savings. As more companies look to move critical business functions like accounting and supply-chain management onto the Internet, the field is set to explode. Credit Suisse First Boston estimates the intelligent traffic management market will reach $3 billion by 2004. Early entrants include Seattle's Internap Network Services, Newton, MA-based Sockeye Networks and netVmg.

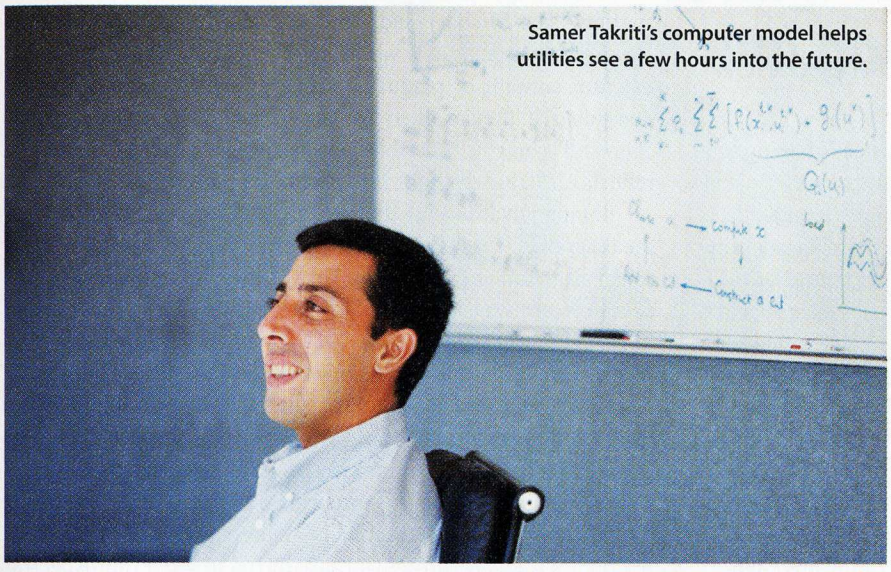
JAMES YANG

OTHERS IN SMART ROUTING

COMPANY	LOCATION
Opnix	Tempe, AZ
Route Science	San Mateo, CA
Network Physics	Mountain View, CA

Strategies for managing the traffic vary somewhat. Internap functions as a virtual service provider, maintaining connections to several backbone carriers like AT&T and Qwest, eliminating the need for customers to deal directly with multiple service providers. In contrast, the customers of newcomers Sockeye and netVmg must maintain their own connections to multiple service providers. The companies monitor both global and local traffic conditions and provide services that optimize outgoing-traffic delivery in real time, based on factors chosen by the customer, such as cost or efficient routing of specific data types. Both companies had only beta customers as *TR* went to press.

In the end, the market will decide the winners and losers in this race. "No one will be able to 100 percent predict the traffic patterns," says Allwyn Sequeira, netVmg's senior vice president of technology. But "what we're doing is bringing more order to the Internet traffic." And that could wind up spelling big bucks for the best traffic cop. —*Erika Jonietz*



Samer Takriti's computer model helps utilities see a few hours into the future.

WALTER SMITH

POWER PORTFOLIO

Financial algorithms could boost utilities' efficiency

ENERGY | Utility companies trade electricity the way brokers trade stocks: buy low, sell high. That requires guessing how much to generate, when to buy power from another firm, how a heat wave will boost demand and so forth. Operations researcher Samer Takriti of IBM's Watson Research Center in Yorktown Heights, NY, hopes a computer model using algorithms from financial markets will reduce the uncertainty and help utilities more efficiently meet demand.

The model crunches weather and historical data about electric loads to predict the hour-by-hour demand for electricity. It also considers the operational costs of a utility's generators—from big nuclear plants that are cheap to run but slow to start and stop to smaller oil or natural-gas plants that are more expensive to run but are quick to start up—and compiles a list of generator scheduling scenarios that maximize revenue. "You can bankrupt the company on a bad forecast," says Joel Gilbert, CEO of Tucker, GA-based consultancy Apogee Interactive.

IBM is one of several companies tackling energy forecasting, and "Nobody pretends to have a consensus opinion about what model is better than another model," says Dan Violette of Summit Blue Consulting in Boulder, CO. Takriti would like to improve his model by enabling the computer to sense when conditions—such as temperature—have changed enough that a new prediction is warranted. "You would like the system to have the intelligence, instead of having people hit the 'solve again' button," says Takriti.

To get there, his model will need more computing power and more sophisticated algorithms—enabling it to handle additional variables such as generators' maintenance schedules and available capacity on the power grid—that could take another year or two, Takriti says. Ultimately, such models might take the guesswork out of energy trading. —*Tracy Staedter*

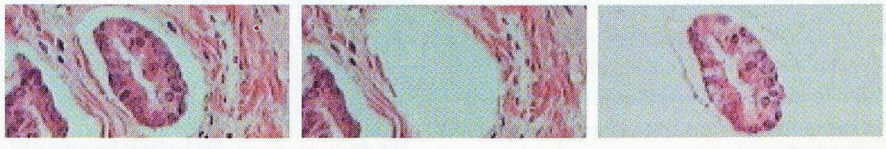
DUSTING FOR CANCER'S PROTEIN "FINGERPRINT"

BIOTECH | **Even before researchers finished sequencing the human genome, many shifted their focus to proteomics, the study of the proteins encoded in that sequence. Understanding how proteins work and how to manipulate them could provide new ways to diagnose and treat disease. This summer, proteomics took an important step toward medical application when the National Cancer Institute and the U.S. Food and Drug Administration began using proteomic tools as part of human trials for new cancer treatments.**

In the three-year program, researchers will use tissue from biopsies to study how patients' proteomic "fingerprints"—profiles of the proteins in particular cells—change during treatment. "This is the first time proteomics is being used during clinical trials with actual biopsy material," says the FDA's Emanuel Petricoin, codirector of the program. It's also the first time researchers will be able to follow health-related changes in a patient's protein profile over time. "I think it's a great idea," says Joshua LaBaer, director of the Institute of Proteomics at Harvard Medical School.

But it's an ambitious idea as well, LaBaer cautions. "I'm worried the technology is not mature enough, and a lot of stuff will be missed," he says. Indeed, detecting and analyzing these fingerprints is no easy task. Using a laser dissection device, the researchers extract cancerous, precancerous and normal cells from a tissue sample; special "protein chips" *(see "Protein Chips," TR May 2001)* are then used to identify hundreds of proteins within each cell. Computers compare such fingerprints from dozens of cell types and hundreds of patients, looking for patterns associated with disease, remission and drug toxicity.

"Right now we aren't making clinical decisions—we aren't yet telling oncologists to change therapy," Petricoin says. In two to three years, though, proteomic tests could be used to guide treatment, alerting a doctor when a drug is causing a toxic reaction, for example, before significant damage is done. —*David Talbot*



Cancer cells (right) and normal cells (center) are separated before their proteins are profiled.

COURTESY OF THE NATIONAL CANCER INSTITUTE

A PICTURE OF HEALTH

New imagers offer an unprecedented view

MEDICINE | X-rays and magnetic resonance imaging are powerful tools in medicine, but neither tells doctors everything they want to know. To get a better picture of the structural effects and chemical details of various diseases, researchers are adapting a technology long used by satellites to study the ground below.

It's called "multispectral imaging," and it uses a camera and certain wavelengths of visible and infrared light to take pictures of moles and other surface structures. It can even photograph internal structures like the brain, say, or a tumor, because some wavelengths can penetrate the body without harming it. By choosing wavelengths tuned to different constituents of biological tissues, such as water and fat, researchers can pick up otherwise invisible details, much as satellites can "see" the heat of a dense urban area using the right wavelengths of infrared light.

Engineers at several universities—many with funding from the National Institutes of Health—are working to develop these imaging tools for medical applications. Because they can operate in real time, multispectral imagers could, for example, help guide doctors during surgery. Alexander Gorbach, a research scientist at NIH's Clinical Center in Bethesda, MD, is building a system to help neurosurgeons distinguish between cancerous and normal tissue in a brain exposed for surgery—based on the fact that light bounces off the enlarged nuclei of cancer cells differently than it does off normal cells' nuclei. The imager could help brain surgeons know precisely where to cut.

The technology could also help doctors get medical data without putting patients under the knife. "That's one of the advantages, that you don't have to remove tissue to get information," says Michael Feld, director of MIT's Laser Biomedical Research Center. Feld is working on a system to determine the calcium content of plaques in arteries, which could tell heart specialists if they're likely to cause problems. Gathering such chemical clues is possible because each type of molecule reflects and absorbs light in a particular pattern.

Taking advantage of that effect could have a big impact on the diagnosis of some common cancers. Sergio Fantini, a professor of electrical engineering at Tufts University in Medford, MA, uses different wavelengths of infrared light to determine oxygen levels in breast tissue—important because tumors use more oxygen than normal cells do. Currently, up to 90 percent of suspicious spots found during conventional mammography turn out to be benign, but, says Fantini, "We hope to discriminate between benign and malignant tumors based on the oxygen level"—possibly sparing hundreds of thousands of women each year from painful biopsies. And researchers at the University of Texas at Austin are midway through a human trial to see if multispectral imaging could replace current tests for cervical cancer. They hope to cut the rate of false positives by as much as 40 percent, which they estimate could save $625 million every year. If such trials prove the medical value of multispectral imaging, doctors could soon see their patients in a whole new light. —*Neil Savage*

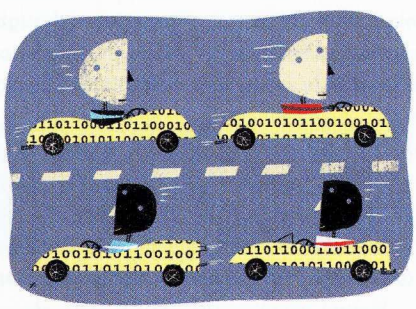
OTHERS IN MULTISPECTRAL IMAGING

RESEARCHER	LOCATION	PROJECT
Daniel Farkas	University of Pittsburgh	Skin cancer detection and endoscopy
Joseph Gardecki	MIT	Alzheimer's diagnosis
Charles DiMarzio	Northeastern University	Blood flow in diabetes and psoriasis

SPEEDY DELIVERY

HARDWARE | Chips inside today's computers process data with ferocious speed. But a computer's performance is limited by how fast data travels between, say, the memory and logic chips. Buses, the devices that move data between computers' components, are notorious bottlenecks. But their reputation could be on the mend, thanks to a consortium of chip and computer-equipment makers created to commercialize a lightning-fast bus technology from Advanced Micro Devices.

The bus, which AMD calls HyperTransport, enables data transfer rates of up to 12.8 gigabytes per second, about 50 times faster than the current standard. While it's hard to quantify the resulting improvement in computer performance, Linley Gwennap, principal analyst at the Linley Group in Mountain View, CA, says that such faster buses are critical to reaping the benefits of the next generation of superfast microprocessors. Today's buses are like a one-lane bridge: if data is going out of a chip, nothing can come in. AMD's new buses provide both an inbound and an outbound link. "You wind up with a mini-network of chips on the motherboard. It allows you to send stuff incredibly fast," says David Rich, general manager of API NetWorks, a consortium member based in Concord, MA.



In addition to its blazing speed, HyperTransport has lower power requirements than today's buses, making it a natural for personal digital assistants and laptops. But the technology's first applications will be in high-performance computing. Graphics-chip maker and consortium member NVidia, for example, incorporated the bus into its chips for Microsoft's Xbox, a graphics-intensive video game system set to ship this month in the United States. Cisco Systems, also in the consortium, expects to ship network routers using the buses within a year. At least when it comes to computers, you won't have to wait for the bus anymore. —*Erika Jonietz*

JAMES YANG

Ron Insana *and* ***Sue Herera*** *on the CNBC Business Center advantage*

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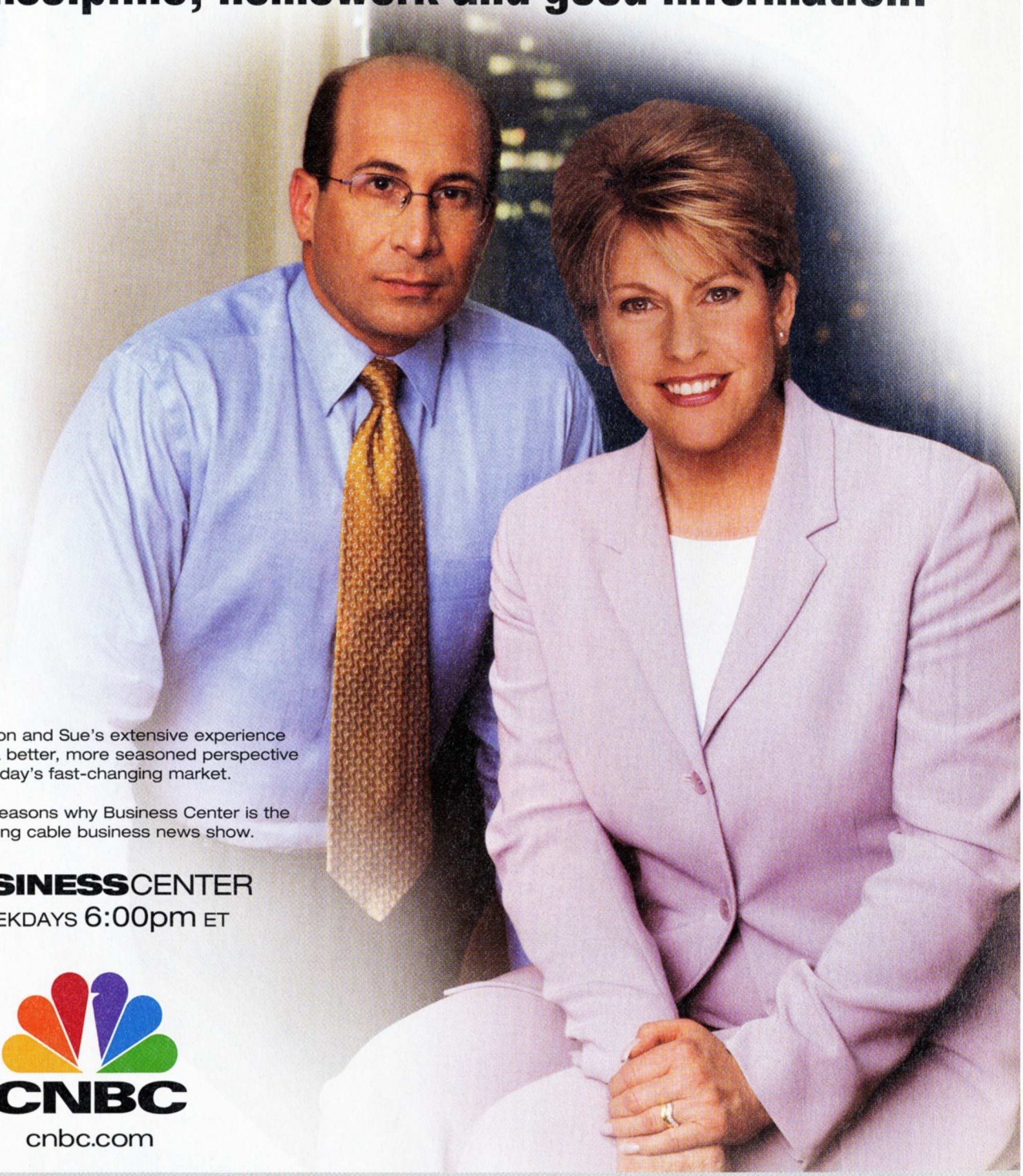

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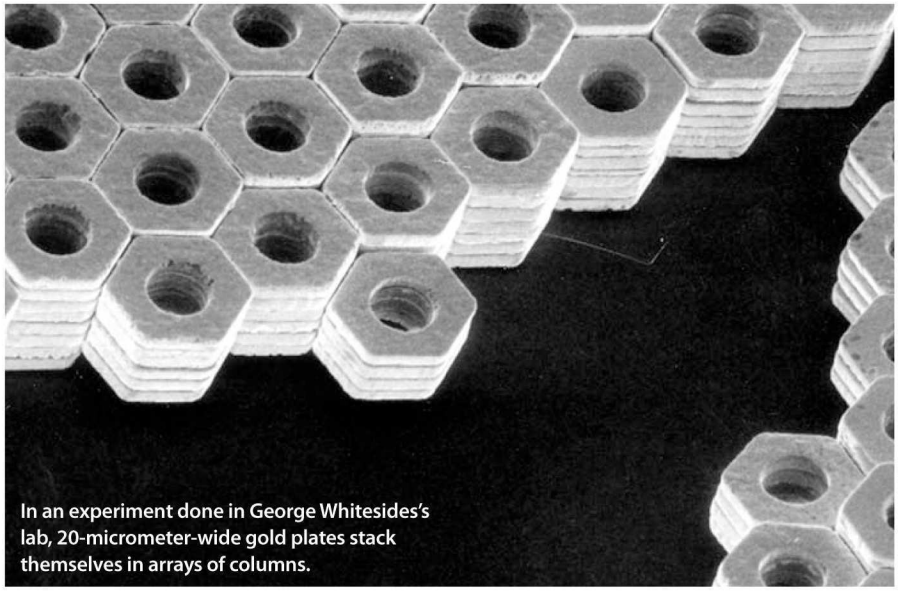


In an experiment done in George Whitesides's lab, 20-micrometer-wide gold plates stack themselves in arrays of columns.

COURTESY OF THE *JOURNAL OF THE AMERICAN CHEMICAL SOCIETY*

SELF-ASSEMBLY

Devices that build themselves are key to nanotech

As researchers begin trying to build devices and novel materials at the nanoscale (a nanometer is a billionth of a meter, the size of a few atoms), they're facing a massive challenge. While it's proving possible, in many cases, to push molecules around to form tiny structures and even functioning devices, efficiently mass-producing anything with nanoscale features is another matter altogether. But what if millions of these nano building blocks did the heavy lifting and assembled themselves into the desired structures—avoiding the use of expensive and elaborate manufacturing instruments?

Self-assembly has become one of the holy grails of nanotechnology, and scientists in numerous labs are working to transform it into an effective nano engineering tool. In some sense self-assembly is nothing new: biology does it all the time. And for decades, scientists have studied "supramolecular" chemistry, learning not only how molecules bind to one another but how large numbers of molecules can team up to form structures; in fact, the concept of self-assembly largely grew out of chemists' attempts to make molecules that aggregated spontaneously into specific configurations, in the same way biological molecules form complex cell membranes.

But now, with an expanding understanding of how molecules and small particles interact with one another, researchers can begin to predict how such elements might self-assemble into larger, useful structures like the transistors on a semiconductor chip. "Self-assembly provides a very general route to fabricating structures from components too small or too numerous to be handled robotically," says George Whitesides, a chemist at Harvard University and pioneer in the field.

To better understand how self-assembly works, Whitesides and his coworkers have recently shown that selectively coating the surfaces of microscopic gold plates with a sticky organic film can, under the proper conditions, trigger thousands of such plates to self-assemble into three-dimensional structures. So far, Whitesides's team has created a relatively large functional electronic circuit using a similar technique. The next step will involve shrinking the circuit to the micrometer scale, creating more complex three-dimensional structures out of silicon. While micrometer-sized electronic components are nothing new—Intel makes them all the time—Whitesides's experiments could provide valuable clues as to how to better manipulate self-assembly.

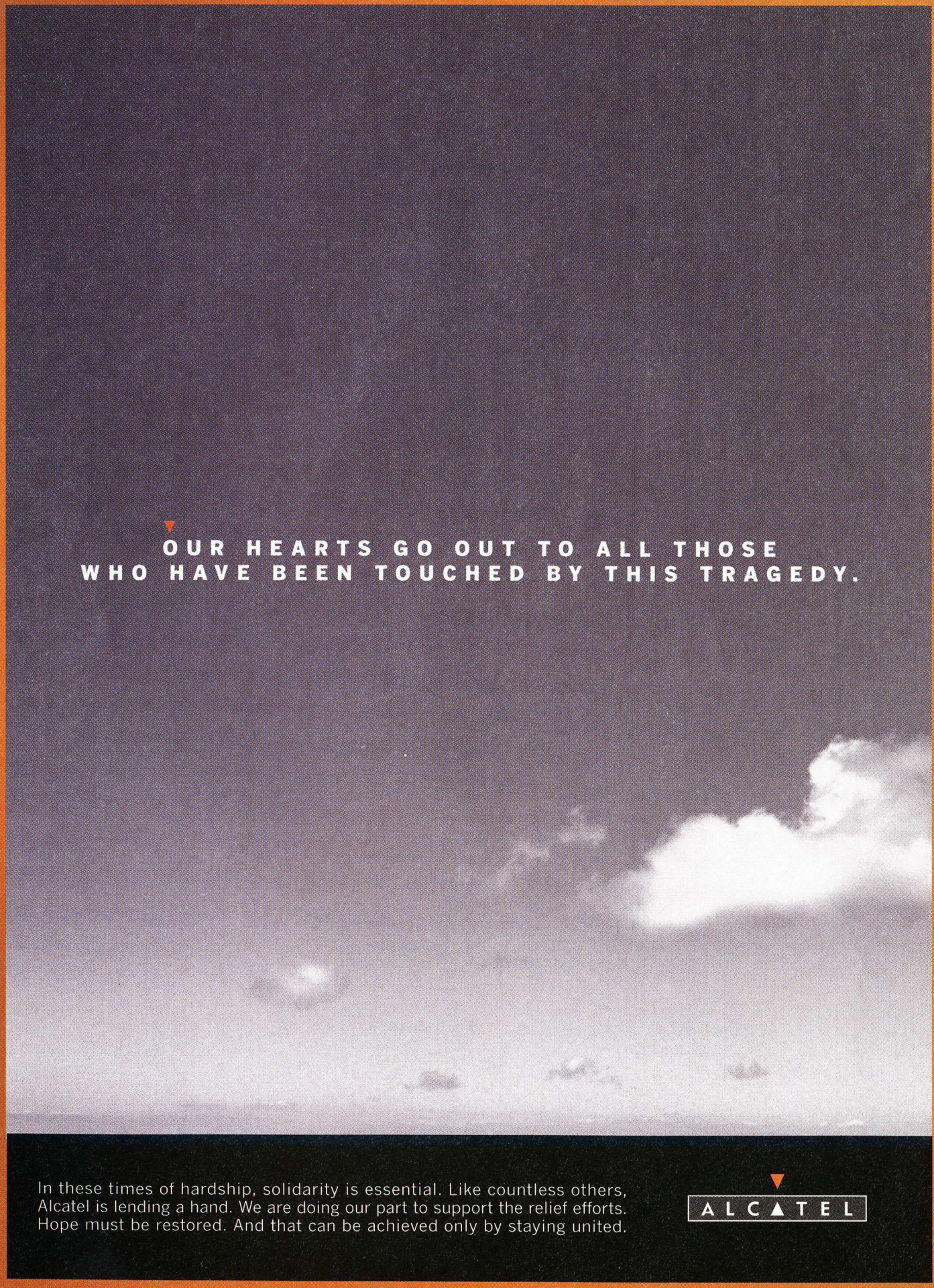
Nature itself is also providing scientists with a model of how to create self-assembling electronic devices. Materials scientist Angela Belcher at the University of Texas at Austin sorted through billions of different proteins to find ones that recognize and bind to different types of inorganic materials. For instance, one end of the protein might bind to a specific metal particle and the other end might stick to the surface of a semiconductor such as gallium arsenide. Given the right prompts, the proteins could direct nano-sized particles of inorganic materials to form various structures.

This past spring, Belcher cofounded a company called Semzyme that plans to create a library of these protein-mediated building blocks. They could have any number of technological applications, in making such things as biomedical sensors, high-density magnetic storage disks or microprocessors.

Chemists at labs such as those of Hewlett-Packard, the University of California, Los Angeles, Yale University and Rice University are also attempting to develop self-assembled molecular computers. If they succeed, however, it will take years.

Meanwhile, less ambitiously, other researchers are making rapid strides in using self-assembly to build increasingly complex—and increasingly small—three-dimensional structures that could be compatible with existing devices. For instance, certain features of a disk drive, like the storage medium, could be created using self-assembly, while larger components needed to connect the device to the outside world would be made using conventional techniques. "We hope that self-assembly will be able to inexpensively replace certain stages in the production of materials and devices, where control is needed at the molecular level," says engineer Christopher Murray of the nanoscale-science division of IBM Research in Yorktown Heights, NY.

If he's right, nano engineering will get a whole lot easier. —*Philip Ball*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Hope must be restored. And that can be achieved only by staying united.
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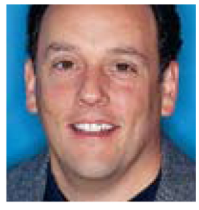
THE MORPHING PATENT PROBLEM

We've certainly learned a lot about stem cell technology recently. Late this summer, my friend George, a prominent stem cell researcher, could hardly get any work done he was so busy explaining stem cell lineages—hepatocytes, myocytes, osteoblasts—to the eager journalists and TV news crews camped in his lab.

It's still too early to tell, but we all can probably learn an important lesson about patents from the stem cell debate as well. In case you missed it, just as President George W. Bush decided to let federally funded researchers study those human embryonic stem cell lines already in existence, the public learned that a little-known private firm—Menlo Park, CA-based Geron—held a proprietary lock on them so tight that federal funding might be nearly moot. The situation was so dire a National Institutes of Health team scurried off to "negotiate" (read beg) for access to the sought-after stem cell lines.

How in the world is one company able to "own" such critical technology? Especially given that much of the work behind Geron's position—led by developmental biologist James Thomson at the University of Wisconsin-Madison—was done at a public university?



Well, it's a tragedy of errors.

First, the federal government deserves blame for dragging its feet in funding human embryonic stem cell research to begin with. Its politically motivated reluctance to get into this area left the door wide open for Geron to demand an exclusive license to the technology when it helped underwrite Thomson's early research in 1995. (While federal funding for embryonic stem cell research was banned from 1996 until the NIH issued new guidelines last year, Geron helped keep the field alive *[see "The Troubled Hunt for the Ultimate Cell," TR July/August 1998].*)

Second, we need to scrutinize the role played by an outfit called the Wisconsin Alumni Research Foundation (WARF), which guards the university's commercial interests in such matters. Most universities have similar technology licensing operations. And in this case, the Wisconsin foundation brilliantly performed its core job: securing a phenomenally broad patent on human-embryo stem cell research and on the stem cell lines themselves—and then inking the exclusive deal with Geron. The problem is that this private group was accountable to no one as the public guardian of a vital monopoly.

These problems were compounded by President Bush's hairsplitting decision to allow research only on existing human embryonic stem cell lines. In so doing, Bush unwittingly strengthened Geron's hand. Because the number of cell lines has now been limited, researchers will be all the more at the whim of WARF and Geron for the next two decades while their patent remains in force. Not surprisingly, the company's stock rose to a six-month high on the strength of its position.

But the situation gets even worse.

The Wisconsin foundation holds patents on not only the five original cell lines developed by Thomson but also the laboratory methods used to produce them. In a press release, a Wisconsin spokesperson said virtually all other embryonic cell lines now in existence fall under the Thomson patent. As a result, Geron can arguably lay claim to the results of any federally funded research involving any cell types developed from the precious stem cell lines originally created by Thomson.

Perhaps the biggest lesson of all, though, surrounds the chronic myopia of the U.S. Patent and Trademark Office in awarding such needlessly all-encompassing patents as it has in this field. By now, if you have followed the stem cell story you undoubtedly know that human embryonic stem cells are undifferentiated cells taken from fertilized embryos that can morph into virtually any of the more than 200 cell types in the human body. In theory, these undifferentiated cells grown in culture could provide an unlimited source of specific, clinically important specialized cells to treat diseases such as Parkinson's and Alzheimer's, or even provide replacements for damaged or diseased bone, muscle, liver or blood cells.

The most dangerous and problematic patents are a lot like embryonic stem cells: they are so broad and undifferentiated they can morph into almost any application they wish.

What's really scary about this, as it relates to patents, is that some patents are a lot like embryonic stem cells—so broad and undifferentiated they can be seen to apply to virtually any research problem in a given area. To borrow from the stem cell lexicon, these patents are pluripotent, or totipotent. They can morph into almost any application they wish to.

The problem with broad patents on such embryonic technology is clear: they wind up blocking the path for other, more specific patents seeking to bring innovations to market. The patent office vitally needs to learn to distinguish between these kinds of embryonic research tools and marketable inventions more akin to the differentiated cells that perform specific jobs in the body.

As legal scholars have documented in other high-tech areas, overly broad patents lead to the paradoxical result that fewer useful products are developed, because they shut other researchers and inventors out of the action. This is likely what will happen with stem cells. That outcome, desired by no one, would be the biggest—and sorriest—lesson of this debate. TR

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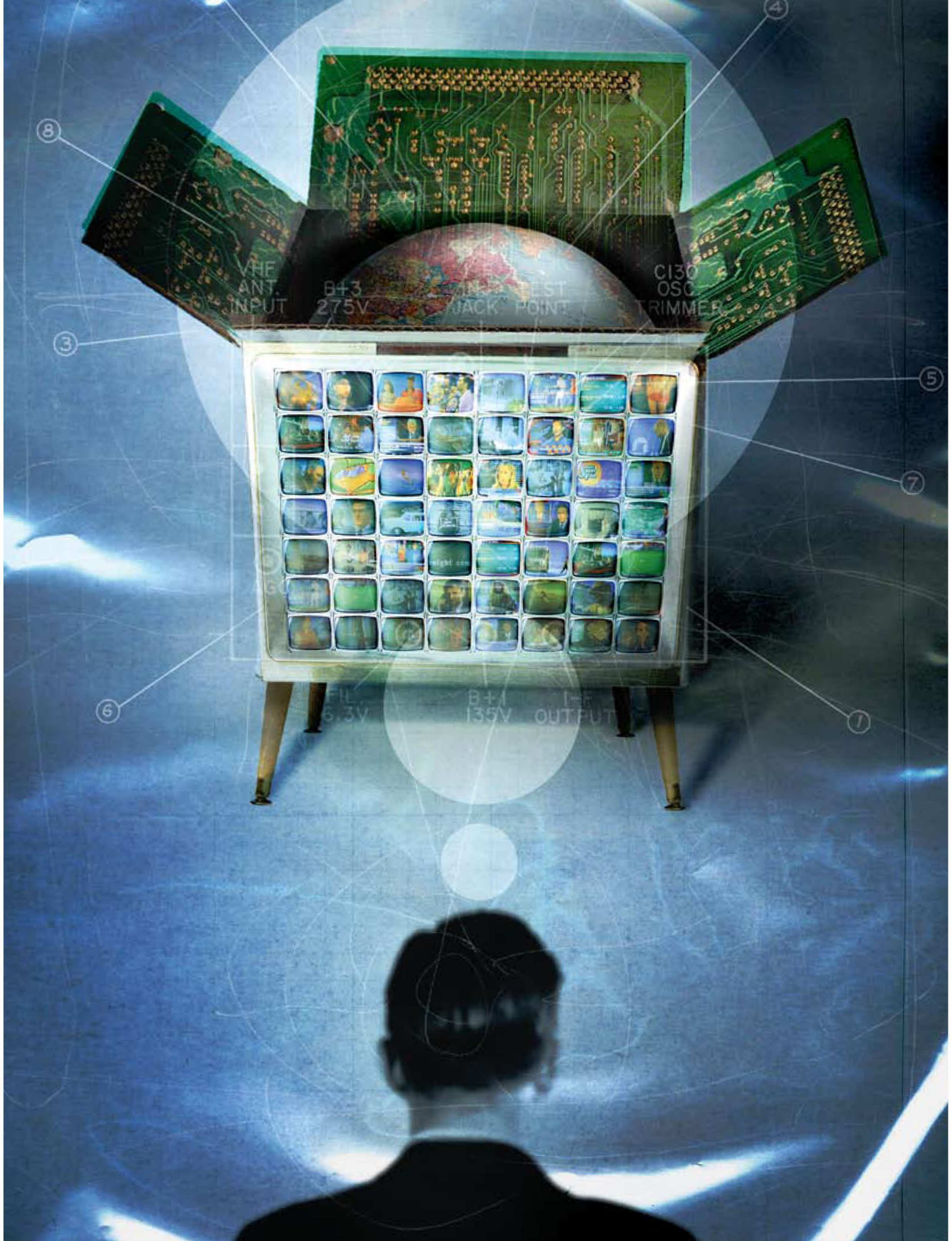
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It's then that you realize you could be watching that big soccer match in Rio de Janeiro, but your cable company isn't carrying it. A Richard Pryor movie would brighten your outlook, but you'd have to rent a video. One of those amateur Internet movies might be interesting, but that means sitting in your stiff desk chair staring at a small screen…and, oh yeah, the movie will take an hour to download. You smirk. After a half-century of television, you're still hostage to a few tired broadcasters.

Stay tuned. Much of the broadcast, reception and display technology needed to let you see whatever show you want, whenever you want, on whatever screen you want, exists. The pieces just have to be improved and linked together in the right way.

Connecting the chain will be no small feat. But it will be forced by a much larger convergence already under way in digital entertainment. As digital movies and television programs become increasingly common, they are morphing with video games, Internet video and music into one uniform stream of digital content. At the same time, the distribution channels for that content—cable TV, satellite and the Internet—are widening into one big broadband pipe to your home.

BY MARK FISCHETTI
ILLUSTRATION BY STUART BRADFORD

What's missing is a commercial platform—a box in your home containing electronics and software that will let you receive the digital entertainment, interact with it and display it on any screen. Your TV, even a digital one, isn't powerful enough, and neither are the set-top converter boxes that receive signals from cable or satellite providers. The need for a radically new platform "has created a massive opportunity for technology companies to innovate," says Banc of America Securities analyst William Bao Bean, who specializes in digital entertainment. A new industry composed of startups and veteran electronics firms is emerging to supply that platform, which could be an advanced set-top converter, a personal video recorder or a souped-up version of a game machine.

And what of the television set? Once the magic box arrives, we will no longer need it.

THE TEST

The technology push applied by this convergence nicely matches the pull consumers are exerting. In decades past we spent our electronic-entertainment budgets on TV sets and got programming free over the airwaves. A "better" viewing experience meant buying a color TV, then one with a bigger screen. By the late 1980s, "better" meant "more," and we bought subscriptions to cable or satellite television.

Today, we receive more channels than we can attend to. And we must wait for the few gems we care to view. What we really crave is "custom TV," which would offer all the digital entertainment we wanted, whenever we wanted it. "We are moving from a subscription model to a usage model," Bean says.

Marketers are continually telling us that if we spend enough money, we can have the future of TV now. But will the next big thing really pass the test of moving us closer to custom TV? Or will it just give us a nicer picture?

Go to your local electronics store and you'll probably hear the same pitch I heard from Mitch, an overly exuberant sales guy. "This is the future of TV right here," Mitch bubbles, pointing at a big-screen Philips Magnavox. "It's home theater, really. And check out these babies: projection TVs. They're really big. Or…," he turns in awe toward the private viewing room, "you can go for a flat, plasma display. The picture is really sharp. It'll set you back $8,000, but man, it's worth it."

Do these contraptions get us the shows we want, when we want them? They have impressively large and crisp screens, but we want a new entertainment experience, not just a fancier image. Test failed.

Undaunted, the salesman swoons over the new "digital TVs," one of which can display that big innovation we've heard about for a decade: high-definition television. But just try to find a digital broadcast *(see "United States Trails Japan, U.K.," p. 38)*. In 1996 the Federal Communications Commission passed a regulation requiring U.S. broadcasters to stop all analog broadcasts by 2006. To date, only a few networks, such as HBO and ABC, are sending digital signals; the rest are in no hurry to start. Still failing.

Okay, so Mitch can't sell me the future of digital entertainment. How about my local cable TV distributor? Maybe it can send me some of that "interactive TV" programming (sometimes referred to as "enhanced TV") I've been hearing about. Whoops: I have to set up my personal computer in the same room as my TV in order to play along with game shows like *Who Wants to Be a Millionaire?* And this ad hoc setup still won't support the real promise of interactive TV, such as clicking on baseball's highest-paid player, Alex Rodriguez, to see his stats when he comes to bat. Or ordering products that appear on a show's set. Or—ultimately—finding only what I want and viewing it right then. The so-called Digital Television Application Software Environment standards needed for such interactions won't be finalized until late this year, and televisions based on them probably won't be available until 2003, according to Lynn Claudy, senior vice president for science and technology at the National Association of Broadcasters. And then, says Claudy, who participates in the international Advanced Television Systems Committee responsible for setting these standards, "the broadcast will have to be digital, and so will your TV." It's 2006 again.

A new industry composed of startups and veteran electronics firms is emerging to supply a radically new platform for custom TV.

CREATING THE MAGIC BOX

Even if you had a digital TV and received an interactive digital broadcast, you would still be limited to programming from your local airwaves broadcasters or cable or satellite TV distributor. Gaining access to all entertainment all of the time requires technology that would let you find specific movies, TV shows and Internet videos, download and store them on a hard drive, and play them whenever you wanted—on any display screen, not just a digital TV.

The race to provide such a component began in 1999, when startup companies TiVo of San Jose, CA, and ReplayTV of Mountain View, CA, introduced the first prototypes, dubbed personal video recorders or digital video recorders. Essentially, they operate like set-top boxes with fat hard drives. The signal from your cable or satellite television distributor passes through the machine's memory en route to your TV. The box records and plays back the signal at the same time. That allows you to pause an episode of *The West Wing*, run to the bathroom for two minutes, then pick up exactly where you left off, the machine playing it from storage as it continues to record the ongoing broadcast. You see the whole show but end at 10:02 instead of 10:00. Or you can fast-forward and catch up. You can even freeze live action to marvel at Martin Sheen's furrowed brow. The early boxes cost $400 to $700, plus a monthly subscription fee of $10 to $20 (or $200 lifetime).

The bigger possibility was that, eventually, you could bypass your local cable company completely. You could tell your digital video recorder to search a large electronic program guide maintained by TiVo or Replay and then download all sorts of shows from all sorts of broadcasters. You could select a 1956 variety show, all of Julia Roberts's movies or the first eight episodes of *Star Trek*. In short, you could have custom TV. Worried, most of Hollywood's major studios, and most of the major cable and satellite TV providers, invested in or partnered with TiVo or Replay, so they wouldn't be shut out if such a service began.

Neither company has fulfilled the grand vision, however. In November 2000 ReplayTV announced it would stop making boxes; digital-media company Sonicblue soon purchased ReplayTV and is integrating its technology into future products. TiVo continues, but with limited service and software. Its box can connect to the Internet, but it uses a narrowband modem, so it cannot support interactive viewing. More importantly, the central store of "all" television shows and movies has not materialized. Subscribers can only get TV shows offered by their cable or satellite providers. And they still must wait until a show is aired to record it. TiVo has not been able to convince media companies to make their content available directly through a TiVo program guide in part because its software cannot prevent consumers from making and swapping unauthorized copies, or stop hackers from stealing the signal. "It is very easy to copy a digital signal and rebroadcast it with no loss," says Carl McGrath, vice president of Motorola's DigiCable division. "The content industry is scared to death, and they should be." So are the distributors.

Seeing the potential to sell a new type of box and attract monthly TV subscribers, Microsoft entered the fray in March 2001, when its competing digital video recorder and service, called UltimateTV, hit retail shelves. It gives consumers DirecTV's satellite programs but feeds them through a video recorder box. The package also includes Microsoft's WebTV software, which lets you connect to the Internet through a phone line and display Web pages and e-mail on your TV. But like TiVo, UltimateTV is too slow to download Internet video. It cannot provide piracy- or copy-protection either.

Motorola is also taking aim at the magic box. It makes more than two-thirds of set-top cable boxes. New boxes in its DCT5000 series, for sale this year, will have more computing power than a digital video recorder and include a broadband cable modem. "It really is a video workstation," says McGrath. The successor device now being developed will have a hard drive for storing and replaying video, turning the set-top box into a broadband digital video recorder.

Nonetheless, Motorola must clear the same copy protection hurdles as Microsoft and TiVo before it can offer custom TV. Protection schemes will likely be part of a box's underlying operating system, which puts the onus squarely on companies like Liberate Technologies and OpenTV that supply platform software to hardware makers like Motorola. The specter of Microsoft dominating this critical arena with its own proprietary operating-system standard—just as it has PCs—seems to have galvanized action. In June, just three months after Microsoft's UltimateTV hit

The U.S. TV Picture

>Broadcast Format

TECHNOLOGY	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Analog TV	Analog signal; picture resolution up to 480 vertical lines	Can be sent through air or cable; can be received on any inexpensive TV	Less clear picture than digital, even at same resolution; can't support interactivity
Standard digital TV	Digital signal; picture resolution at 480 vertical lines	Sharper picture than analog, even at same resolution; supports interactivity	Few digital broadcasts to date; 91-centimeter set costs $1,100
High-definition TV	Digital signal; picture resolution at 1,080 vertical lines	Much sharper picture than analog or standard digital; supports interactivity	Few digital broadcasts to date; 91-centimeter set costs $1,700

>Possible Platforms

TECHNOLOGY	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Digital video recorder	Receives signal from cable or satellite, feeds to TV or display	Records and plays simultaneously; stores up to 35 hours; can access Internet	Average $350, plus $10 monthly subscription; can't play video games or receive Internet video
Digital set-top box	Receives signal from cable or satellite, feeds to TV or display	May be provided by TV distributor for a few dollars a month; can access Internet	Can't record or store TV; can't play video games or receive Internet video
Game system	Plays video games on TV or display	Has PC-level processor; can access Internet; can play Internet video and DVDs	Can't receive, store or record TV shows; average $300
Personal computer	Receives data over Internet, processes and feeds to monitor	Can play Internet video, DVDs and video games	At least $900; receiving and recording TV requires costly added hardware and software

>Displays

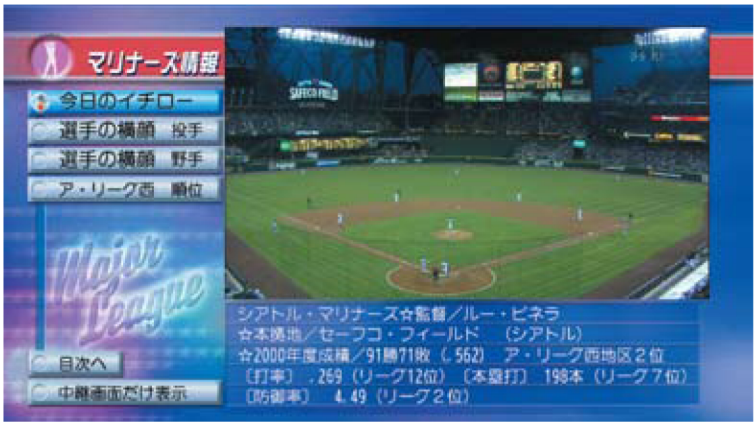
TECHNOLOGY	DESCRIPTION	ADVANTAGES	DISADVANTAGES
TV set	Cathode-ray tube	Inexpensive: 91-centimeter set costs $750 analog to $1,100 digital	Bulky, heavy; square screen only
Flat screen	Cathode-ray tube	Less distortion and glare; square or wide screen	Bulky, heavy; expensive: 91-centimeter display costs $1,300 analog to $2,200 digital
Plasma display	Gas-filled cells emit light when a charge is applied	No distortion or glare; very thin and light; square or wide screen	Very expensive: 107-centimeter (smallest) display costs $8,000

the market, two dozen companies, including Motorola, TiVo, OpenTV and Liberate Technologies, announced they had formed an alliance based on the open-source operating system Linux. This TV Linux Alliance aims to establish specifications for interoperability that would let consumers buy whichever television, set-top box or digital video recorder they wanted, and subscribe to whichever television distribution service they wanted—and be sure everything would work together. Linux would thus become the operating system for all platforms—UltimateTV excepted. Only Microsoft has the power and cash to fund deployment of an operating system by itself, says Bryan Sparks, CEO of Lineo, one of the platform firms involved in the alliance. "The alliance makes sure the rest of us don't miss an opportunity to compete with them."

Although digital video recorders and set-top boxes are the front-runners, a third contender threatens: the video game system. Sony's PlayStation 2, for example, already has a microprocessor that surpasses those in digital video recorders, plus a video processor robust enough to control a TV set—and it recently added Internet access and online gaming options. This month, Nintendo was to release a similarly powerful machine called the Gamecube, and Microsoft was to begin selling the Xbox in the United States. All three devices lack tuner cards to receive TV signals and hard drives to store and replay shows. But these capabilities could be added, and as broadband expands, online gaming could begin to erase the difference between games and TV shows. Robert Bach, chief Xbox officer at Microsoft, says the company already envisions "episodic content," where new scenarios, characters and storylines are injected as online games proceed. "It is much more like producing a show than creating a game."

BATTLE OF FOUR

Regardless of which platform prevails, its emergence will mean that technology finally passes the test of being able to generate, distribute and display a broadband stream of digital entertainment. But we still won't have custom TV until companies find the best business model for integrating digital content, distribution and the platform. To get there, a media company, broadcast company and consumer electronics company could create a strategic alliance. Or a huge corporation could try to provide it all. Within the last year, corporate jockeying has become feverish.



COURTESY OF NHK

United States Trails Japan, U.K.

Digital television is being implemented widely in Japan and Britain. But it's still uncommon in the United States. Broadcast standards, cost and a laissez-faire U. S. regulatory environment make it difficult to close the gap. Indeed, it could be decades before the United States fully enjoys digital TV.

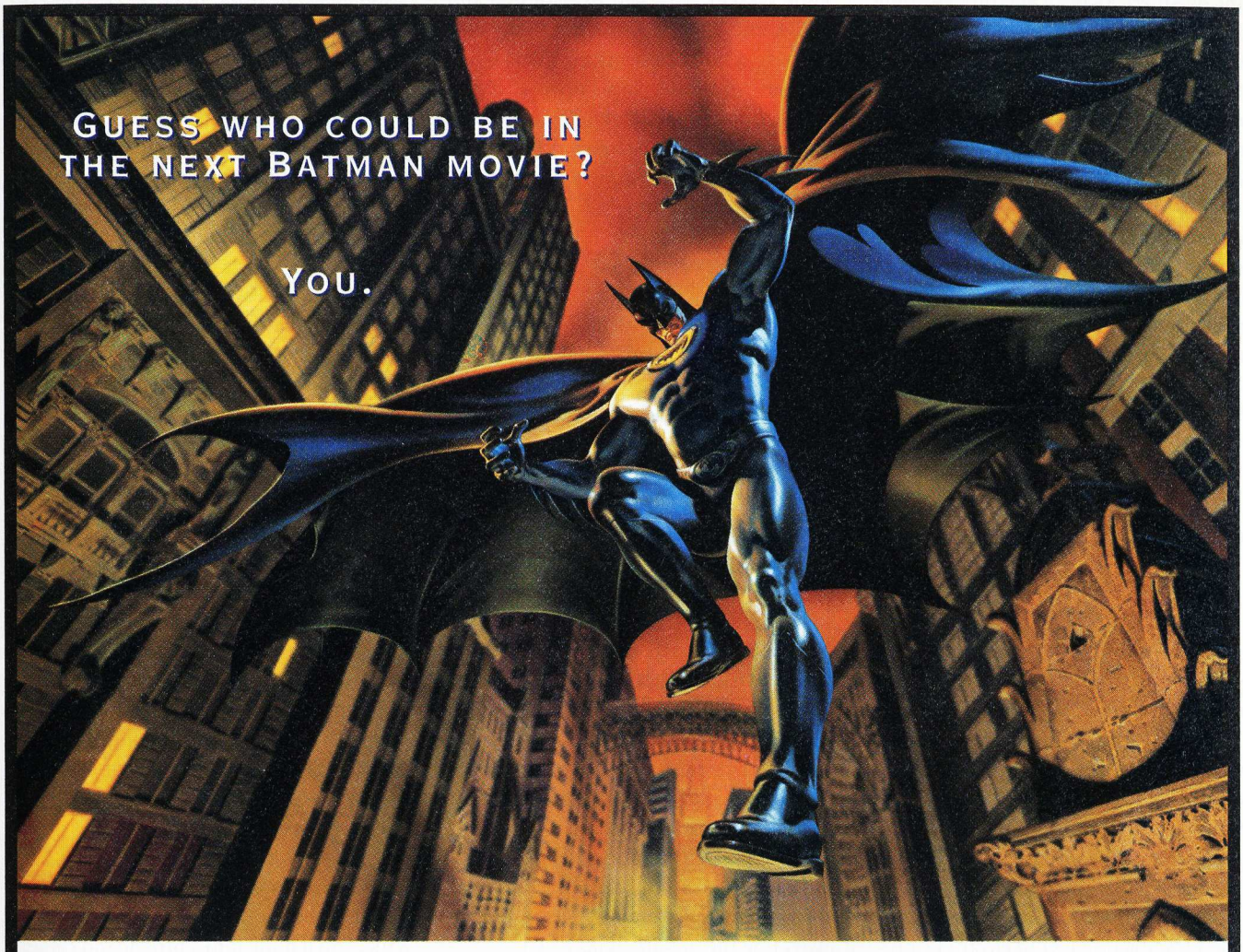
Japanese broadcasters were the world's first to offer digital TV. In 1989, the Japanese public broadcasting network, NHK, launched an experimental one-hour broadcast dubbed "Hi-Vision." Today, 14 million households receive one or more digital channels from various networks, broadcast 24 hours a day by satellite. The Japanese government has already established a second-generation Integrated Services Digital Broadcasting standard and pushed broadcasters and consumer electronics companies to agree on technical protocols. As a result, manufacturers such as Panasonic and Sharp sell competing set-top boxes that can receive digital signals from all broadcasters, giving viewers inexpensive access to many shows. Takeatsu Yamauchi, an associate director of NHK, says digital TV should prevail nationwide by 2006.

The United Kingdom also moved quickly to implement digital television. In 1998, British media company ONdigital began providing terrestrial digital service; now about 20 percent of British homes subscribe to digital TV. That quick ramp-up is partly due to nationwide adoption of the Digital Video Broadcasting standard, which allows consumers to view a digital signal on an analog "tellie," simply by adding an inexpensive converter. Converter prices have dropped to a pittance in Britain—Europe's digital-TV leader. The United Kingdom's Independent Television Commission aims to complete a nationwide changeover by 2010.

Had the United States used either Japan's or Europe's standards, it wouldn't be frozen in digital paralysis. But it adopted "eight-level vestigial-sideband modulation," a standard picked by an industry consortium, the Advanced Television Systems Committee. This choice favors a "high-definition" digital scheme—the most costly and difficult service to implement. Unlike the "standard" digital signal used in the U.K., the data-intensive U.S. signal requires new set-top receivers and expensive televisions.

This has created a chicken-and-egg situation that may prevent further progress: Consumers aren't buying the pricey sets partly because there is not enough digital programming. Yet broadcasters don't want to install the expensive equipment needed to send digital signals until enough consumers have digital TVs. FCC rules do nothing to resolve the problem; they require broadcasters to turn off their analog signals by 2006—but only if 85 percent of the households in their viewing areas can receive digital TV. Any less, and the deadline drifts further into the future until that penetration is reached. As of June, less than one percent of U.S. homes had digital TVs, according to Lynn Claudy, senior vice president for science and technology at the National Association of Broadcasters.

The standoff is likely to continue. Congress could impose the 2006 deadline regardless of TV penetration. Alternatively, the government could require TV makers to include digital receivers in analog TV sets. Market-minded FCC chairman Michael Powell may be reluctant to impose regulations, Claudy says; but if the government simply lets the marketplace decide, he adds, "the learned estimates are that a changeover to digital TV could be a 20-year transition."



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(S01)

Banc of America's Bean and other leading analysts suggest that four far-flung companies each have a shot at becoming the kingpin of custom TV: AOL Time Warner, News Corporation, Microsoft and Sony. Assessing their moves suggests a lot about television's future.

AOL Time Warner holds tremendous content, and Time Warner Cable is one of the nation's largest distributors. All AOL Time Warner is missing is a magic box. It has a start: AOLTV, begun in mid-2000, is an attempt to bring Internet services such as e-mail and instant messaging to the television, similar to Microsoft's WebTV. It includes an on-screen program guide that could form part of the software needed for a magic box, but it lacks the hardware.

Tomorrow's TV could function as the home's central controller, directing the security system, appliances, computers and wireless devices.

News Corporation is another vast content empire, and Rupert Murdoch has a worldwide assortment of cable networks, broadcast television stations and direct-broadcast satellite services. In May, the company became the largest shareholder in Gemstar-TV Guide International, the world's leading provider of electronic program guides, notably the electronic version of *TV Guide*. But like AOL, News Corporation doesn't have a magic box.

Microsoft has ubiquitous software and two hardware choices: UltimateTV and the Xbox. But the regime has little content, and it falls short in distribution. It's no secret, however, that Bill Gates has a keen interest in building a low-earth-orbit satellite network. And Murdoch has courted Gates as a potential bidding partner for DirecTV. If Murdoch and Gates worked together, both companies could complete the digital-entertainment chain. News Corporation and Microsoft both declined to discuss strategy for this story.

That brings us to Sony. It has plenty of content (Sony Pictures, Sony Music), and plenty of hardware and software. Sony's platform strategy is clear: turn the PlayStation 2 and its successor, PlayStation 3, into the magic box. It's got distribution too. In late May Ken Kutaragi, CEO of Sony Computer Entertainment, announced that Sony Entertainment had formed a strategic alliance with none other than AOL Time Warner. Sony gets distribution and AOL Time Warner gets a box. Sony also announced that networking giant Cisco Systems would develop software to give PlayStations broadband Internet access. Other plans include technology to let Sony video camera users upload their movie creations through the company's Vaio laptop computer or PlayStation 3 onto its So-Net Internet portal, where any subscriber could retrieve and watch them. "You could even broadcast your own show live," says Masaaki Oka, a producer in Sony's creative-development department, "or create your own online video game."

Sony bills such moves as creating a new world of broadband entertainment "through the fusion of games, music, movies, and broadcasting." But critics question whether any one company could corner the digital-entertainment industry. "It's logical for [Sony] to try," says Claudy, the National Association of Broadcasters' technology guru. "But they have different core competencies and may not be good at providing the missing links."

The most likely outcome, he and other experts say, is a few giant companies that compete by offering custom TV services. Which package consumers choose will depend largely on price. "The cable and satellite companies are not sure how much consumers might pay," Claudy agrees. "Eventually, the enigmatic desires of consumers will become clear. That will drive up volume, which will drive down cost."

"THE LAST 12 FEET"

Once companies integrate digital content and distribution with a platform, we might finally have custom access to all TV shows, movies, music and online gaming for a low price. But it may not stop there. Since a magic box will accept broadband, it could become the lauded gateway to the home for everything digital, including Internet and telephone. And because it will have an operating system that can control peripherals, it could function as the home's central controller, directing the security system, appliances, heating, desktop computers and all sorts of wireless devices.

One of the first real-world trials of such a system began in August, in Ajax and Pickering, Ontario, just east of Toronto. Rogers Cable, the local cable provider, installed small silver-and-black boxes in 50 subscribers' homes. A Linux-based networking platform made by Ucentric Systems of Maynard, MA, connects each home's computers and appliances to each other and the Internet. The system can provide television, Internet and telephone services on all TVs, plus voice mail and e-mail on all telephones and computers. The Ucentric unit does not yet have digital-video-recorder capabilities or its own electronic programming guide, however, and it can't receive digital TV signals—so custom TV remains out.

It's not the magic box, but it's an indication that the technology is within reach. That's why, says Bean, "the battle in broadband distribution is no longer 'the last mile' to the home, it's 'the last 12 feet' inside that home"—delivering not just bandwidth capacity but a custom broadband experience people can enjoy from a comfortable seat in any room.

The day that arrives, you'll go to the electronics store and buy a "home gateway" box the size of today's VCR for maybe $300. You'll hook it to a broadband cable, then connect it to your wired or wireless home network. You'll call the cable provider and sign up for its custom-TV digital recording service for maybe $50 a month. You'll hang a flat plasma display (prices will have dropped since Mitch's day) on the living-room wall and connect it to a wall socket that also taps into the home grid. You'll put modest displays in other rooms, too. As you leave the bedroom you'll say "off" to its screen, and as you enter the kitchen you'll say, "Screen, show me my stock numbers." During a commercial you'll use a little wireless remote to instruct the hidden gateway box to find, download and play an original *Star Trek* episode. When the episode ends you'll grab the game controller off the coffee table, become Captain Kirk on the plasma screen and engage in a live, online dogfight in the Neutral Zone with an opponent from Tokyo.

And you'll wonder: will anyone buy that old "TV" stashed with the other junk for your tag sale Saturday? Hmm. Maybe some collector of obsolete technology.

Our condolences

to the families and friends of
all those lost on September 11th,
including those from our own Compaq family.

Our respect and admiration

to the rescue workers for their courage and inspiration.
And to the people of NewYork City and Washington D.C.
for their perseverance and strength of character.

Our gratitude

to our employees for all their efforts
in helping the Red Cross and the United Way.

We are never stronger than when
we stand together. And we've never
been stronger than we are today.

COMPAQ

BY STEPHEN S. HALL

Photographs by Beth Perkins & Misha Gravenor

ADULT STEM CELLS

The medical promise and political tribulations of embryonic stem cells have been grabbing headlines, but stem cells derived from adult tissues—not from embryos—are speeding toward the clinic.

PERKINS

Healing hearts: Bradley Martin's studies show that adult stem cells might be able to repair heart attack damage.

The morning began with a first gamy whiff of what lay in store. Shortly after 9 a.m., Bradley Martin, his assistant Jin-Quang Kuang and a researcher named Ellen Flynn marched along a dimly lit, institutional-tiled corridor at the Johns Hopkins Hospital in Baltimore. After pausing to take a deep breath, they pushed through a green door and entered a small room where several robust Yorkshire pigs greeted them with braying squeals and frothing curiosity. Flynn wheeled a heart-imaging echocardiogram machine into the narrow aisle between the cages, and then Martin, a flimsy yellow surgical gown covering his blue jeans and sports shirt, stepped gingerly into one of the cages and gently wrapped an arm around the huge porker, a gesture that wavered between a hug and a headlock. "All those years of graduate school," Martin grunted over his shoulder, "are finally paying off."

Spending your morning wrestling a 180-kilogram pig into position and holding it steady, while a colleague rubs a jelly-coated probe over the animal's chest in search of a good echocardiogram signal, against deafening squeals of porcine protest and the in-your-face odor of big animals kept in close quarters—that's not exactly how most people imagine the world of cell biology. But then Martin is not interested in ordinary cells—or ordinary biology. His foray into the animal room represents what could be one of the last steps in readying a futuristic form of coronary medicine for testing in humans. If all goes well, those human studies could begin as early as the end of this year.

Martin, a sandy-haired, good-humored senior researcher at Baltimore-based Osiris Therapeutics, has been paying weekly visits to this room for six months. It is a cardiac ward of sorts: all of the pigs in the room have suffered heart attacks. Some of them, however, have subsequently received a highly unusual form of treatment, an injection of stem cells—specifically, an adult form of these versatile progenitor cells isolated from bone marrow. It is Martin's hope that these special cells, known to biologists as adult mesenchymal stem cells, have grown and transformed themselves within the pigs' hearts to form new, healthy tissue right at the site of injury.

Indeed, it is the uncanny ability to zero in on areas of physiological damage and then to organize the process of healing and repair that makes these and other kinds of stem cells so laden with medical possibility. Most of the cells in the body are specialized to perform specific functions in specific tissues, but stem cells—found both in embryos and in various locations in the adult body—can form a number of different tissues and so could in theory be used to treat a vast array of diseases. Rebuilding hearts after heart attacks, regenerating livers ravaged by cirrhosis or viral disease, reconstructing damaged joints, seeding the brain with fresh neurons to reverse the effects of Parkinson's disease and Lou Gehrig's disease—those are just some of the fantastic medical promissory notes that doctors predict these remarkably potent cells will ultimately redeem.

Still, a professional rivalry has emerged between researchers who think stem cells derived from embryos have the greatest medical promise and those who are instead betting on cells derived from adult tissues. Embryonic stem cells are able to form more than 200 separate and distinct tissues, while adult stem cells are "multipotent," able to form just a limited number of tissues; the Osiris cells, for example, have only six possible fates. But because of their controversial origins in embryos left over from in vitro fertilization, embryonic stem cells have met fierce public opposition from religious and political conservatives that has slowed funding and research opportunities. And while President George W. Bush's August decision to allow limited federal funding for embryonic stem cell research could help open the field, its political future remains murky.

While this public drama has been playing out, embryonic stem cells' supposedly less potent and seemingly less glamorous biological cousins, the adult stem cells, have quietly been writing a fascinating story of their own—a story that in many ways is more advanced, clinically and commercially, than the embryonic stem cell story. While federal funding bans and policy debates have relegated human embryonic stem cell research to labs at a handful of companies, in the parallel universe of adult stem cell research has come great progress, with both companies and academic scientists publishing one striking finding after another. On the strength of those studies, a number of human trials using adult stem cells have been launched in the past two years, with several more high-profile experimental treatments scheduled to begin human testing within the next year.

Sprinkled in tissues throughout the body, from just below the surface of the skin to deep redoubts like the liver and bone marrow, adult stem cells are not, critics say, the answer to every ill. "For certain diseases, adult cells appear very promising, for hepatic and cardiac diseases in particular," says Ronald McKay, a researcher at the National Institutes of Health. "However, if you're asking for a solution to Parkinson's disease or diabetes, I would say the cells that offer the best way are fetal and embryonic." Still, in the unforgiving crucible of clinical studies, where medical potential meets the fickle realities of the human body, adult stem cells are already being tested, while the initial use of embryonic stem cells in humans is perhaps three to five years away.

While a number of biotech companies have adult stem cell research programs *(see "Adult Stem Cells at Work," p. 47)*, Osiris has been especially aggressive about taking the cells into human trials. Since 1999, for example, doctors working with the company have been testing the ability of mesenchymal stem cells derived from bone marrow to help patients with cancer more quickly rebuild their blood and immune systems, which can be damaged by chemotherapy. In these studies, the mesenchymal stem cells were intended to enhance traditional bone marrow or umbilical-cord-blood transplants. "What we can say so far," says University of Minnesota professor of pediatrics John E. Wagner, who heads one of the studies, "is that we have seen no negative side effects, and we have the impression that it's faster."

Recent animal studies emerging from academic labs have underscored the major take-home lesson about adult stem cells in the past year or so: these cells are much more biologically versatile, and capable of adopting many more cellular fates, than anyone previously thought. Last May, pathologist Neil Theise of New York University and stem cell biologist Diane Krause of Yale University and their colleagues published a report in the

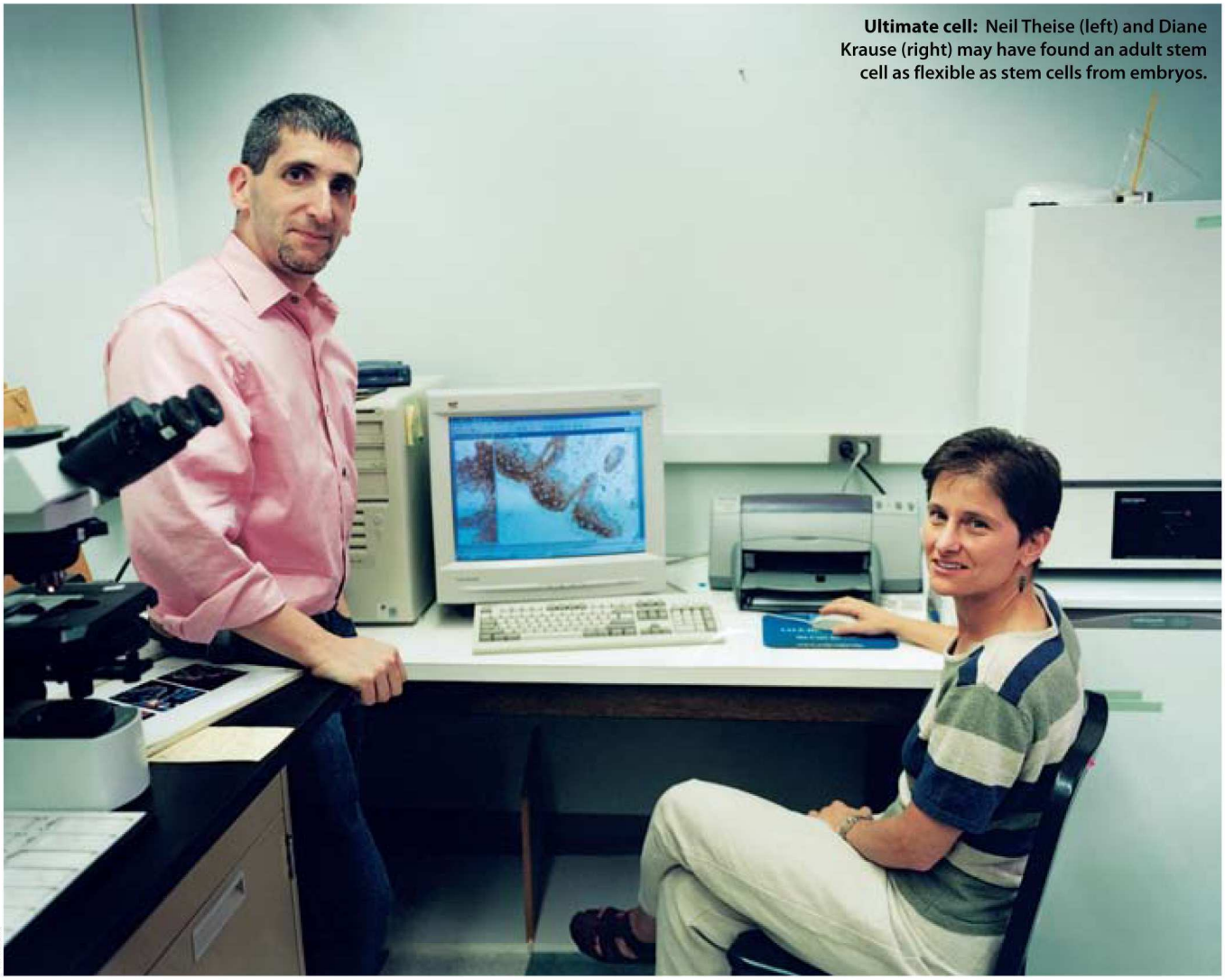
journal *Cell* claiming that an adult stem cell from the bone marrow of mice had the capacity to form multiple tissues—blood, lung, liver, stomach, esophagus, intestines and skin. Theise believes these adult stem cells are as flexible as the embryonic kind, and he refers to them as the "ultimate adult stem cell." And a team led by Freda Miller of McGill University in Montréal recently published work showing that adult stem cells plucked out of the skin, an easily accessible site for harvest, can develop into fat, muscle and neural cells.

Another similarly surprising wrinkle in the adult stem cell story has emerged in the last year in research at Stanford University and the National Institutes of Health. The lab of Eva Mezey at the National Institute of Neurological Disorders and Stroke, for example, has shown that, in mice, transplanted bone-marrow-derived stem cells can migrate to the brain and develop into cells with characteristics of neurons and other types of brain cells. It is part of a string of intriguing, but far from definitive, experiments suggesting that the fate of adult stem cells is determined to an enormous degree by the local environment in which they are placed.

Skeptics warn that stem cell experiments in mice don't automatically translate into human biology. Still, all these studies reinforce the notion that the adult body maintains a reserve of stem cells, certainly in the bone marrow and probably in many other tissues as well—although the supplies seem to dwindle with age. "They seem to be part of a natural repair system, so that when you damage a tissue, they come from the marrow in large numbers," says Darwin J. Prockop, director of Tulane University's Center for Gene Therapy in New Orleans, LA. In other words, adult stem cells appear to act as the body's on-call, 24-hour-a-day microscopic medical dispensary for wound repair.

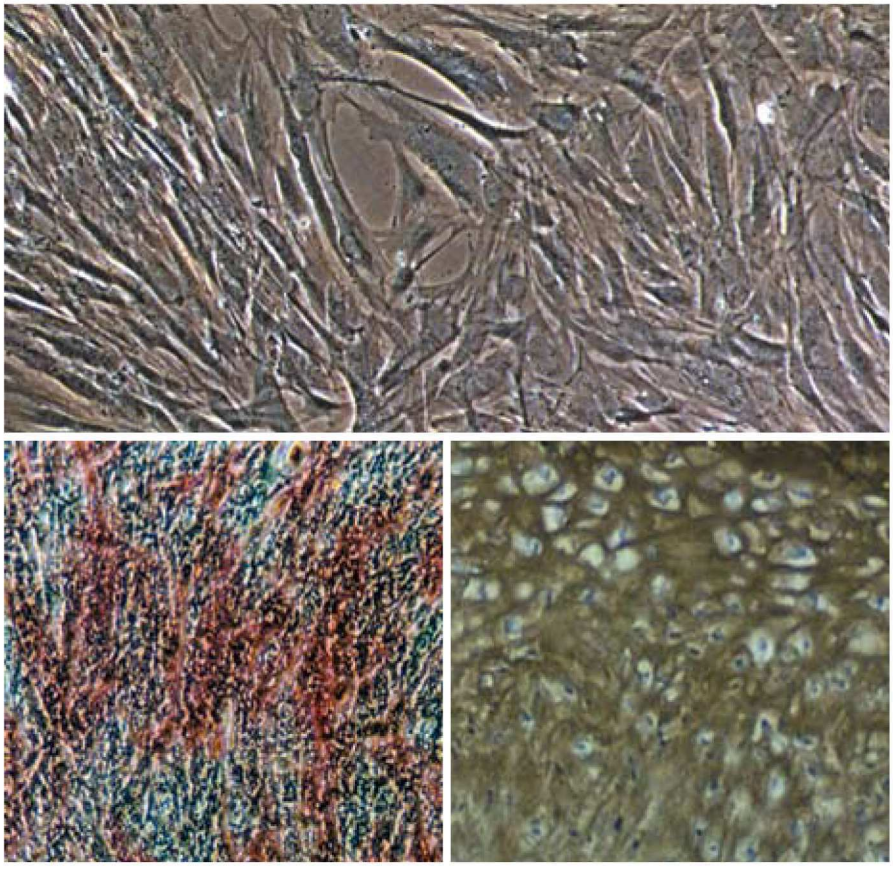
As a body part, the bone marrow has never inspired the kind of rapturous Shakespearean prosody lavished on, say, the heart, liver, brain or even spleen; for the better part of recorded history, it's been of greater value in a soup pot than in the clinic. But this spongy matrix of tissue, encased as in a safe by bone, is increasingly being recognized as a guarded physiological repository for some of the body's most precious jewels—namely, cells that can differentiate into many other tissues. Indeed, adult stem cells from bone marrow have actually been a prominent and respectable feature of medicine for about four decades. It's just that for much of that time, no one referred to the use of them as "adult stem cell therapy."

Human bone marrow transplants, first attempted as a treatment for blood cancers, achieved routine success by the 1970s. That success occurred, it is clear now, because the recipients



Ultimate cell: Neil Theise (left) and Diane Krause (right) may have found an adult stem cell as flexible as stem cells from embryos.

PERKINS



PHOTOGRAPHS COURTESY OF OSIRIS THERAPEU-

Biological chameleons: Adult stem cells found in the bone marrow (top) can develop into several types of cells, including those that form bone (bottom left) and cartilage (bottom right).

received, in the slurry of donor marrow infused into their bodies, "hematopoietic" stem cells—that is, progenitor cells that possess the ability to specialize into all the various cell types of a healthy and whole blood system. In this case, one mother hen of a blood cell gives rise to red blood cells, different types of white blood cells with immunological function, platelets and all the other components of blood.

But the bone marrow, it turns out, also contains another important type of adult stem cell that can meet distinctly different cellular fates—one that has the potential for turning into far more than various types of blood cells. In early 1990, a developmental biologist at Cleveland, OH's Case Western Reserve University named Arnold Caplan, his colleague Victor Goldberg and his then postdoc Stephen Haynesworth isolated a surprisingly versatile stem cell from the bone marrow. The mesenchymal stem cell, so called because it arises out of an embryonic layer of tissue known as the mesenchyme, possesses the ability to form, not only bone and cartilage, but also muscle, tendon, fat and stroma, the weblike matrix of tissue inside bones. In 1993, Caplan and Goldberg helped form Osiris (Caplan is no longer associated with the company).

Osiris relocated to Baltimore in 1995, and its headquarters is now located in a low-slung, renovated brick warehouse in the Fell's Point section of the city that abuts the busy harbor. By patenting and working on the technology in the early 1990s, Osiris got a head start in reducing the harvesting and culturing of stem cells to practice and now is shipping bags of the cells to more than a dozen clinical centers. The process basically works like this: A doctor draws about 25 milliliters of marrow through a needle from a donor's bone, typically the pelvic bone. The desired mesenchymal stem cells are not exactly plentiful—by Osiris's estimates there's only one of them in every 10 million marrow cells—but they can be plucked out by a combination of centrifugation and proprietary cell-sorting technology. Once isolated, these cells are prodded to divide in cell culture flasks to produce about 500 million stem cells per intravenous dose and then frozen in liquid nitrogen.

Osiris scientists have learned that, by altering the culture conditions, they can nudge these stem cells toward various fates—as, for instance, muscle or cartilage or bone. (For clinical use, the stem cells are shipped in an undifferentiated form.) Interestingly, the cells don't just respond to biochemical cues but decide their fates based on physical cues as well, including the three-dimensional environment and even mechanical forces, such as the tension and flexion of joints during walking—which helps explain why the same cells can form such different tissues, depending on where and how they're implanted in the body. "We just put them in the right place, and the body sends the signals," said company president Annemarie B. Moseley.

When Osiris first began human tests in 1999, patients donated their own marrow, and then company scientists would isolate stem cells and culture them for about eight weeks before injecting them back into the patients. Now, it's beginning to look as though cells harvested from unrelated donors might work in *all* patients, opening the door to a universal cell supply that would not create problems of immune rejection.

In the course of assessing the cells in animal trials, Osiris stumbled upon a totally unexpected phenomenon. According to company scientists, these mesenchymal stem cells are conspicuously denuded of several molecular markings that typically provoke an immune response or even trigger transplant rejection. What's more, the cells may secrete a factor that actively inhibits the immune system. The cells, in other words, seem to deploy a biological stealth technology to remain immunologically invisible.

This observation stunned Osiris researchers. "We were flabbergasted," says senior scientist Frank Barry. "We still are." Many scientists remain unconvinced the phenomenon is real. One prominent stem cell researcher, who asked to remain anonymous, says, "I think all of that is hugely exaggerated." But a clinician using the cells who has seen Osiris's in-house data on them told *Technology Review* "it appears to be true." If so, it not only means patients could avoid the painful extraction of immunologically compatible bone marrow, but that the commercial preparation of universal cells would be much more economically attractive to a company. Two large groups of patients who potentially stand

to benefit are heart attack victims and people whose joints are worn down with osteoarthritis.

Heart disease is the leading killer in the United States, and there are more than one million heart attacks a year in the United States alone. As a result, heart disease has been one of the most intense—and impressive—areas of adult stem cell research in the past year.

Last spring, two separate groups, one at Columbia University and the other a collaboration between New York Medical College in Valhalla, NY, and the National Institutes of Health, published studies showing that heart attacks in rats and mice could be repaired by injecting adult stem cells in or near the injury. Now Osiris is trying to do the same with pigs. In the first round of experiments, veterinary surgeons at Johns Hopkins performed open-heart surgery on the animals and tied off the left anterior descending coronary artery, which feeds the main pumping chamber of the heart, for one hour, triggering a heart attack. After two weeks, Osiris researchers then injected about 50 million mesenchymal stem cells directly into the hearts of five test animals. The cells were genetically tagged with a marker so they could be traced in the body, and these pigs, as well as half a dozen control animals, were closely followed for up to six months.

All the pigs that did not receive stem cells died within a month or two of their heart attacks. Autopsies showed that their hearts developed extensive scarring at the sites of injury, and that the organs had become excessively large and distorted in an attempt to compensate for diminished pumping capacity. Eventually, the wall of the heart thinned and heart failure ensued. For the pigs that received stem cells, however, it was a different story. The stem cells zeroed in on the injured cardiac muscle, took up residence in and around the scar tissue and literally remodeled the damaged heart. They seemed, in fact, to interrupt the typical progression toward a lopsided (and prognostically grim) cardiac architecture.

Here are the caveats: the stem cells that take up residence in the scar tissue have the markers of cardiomyocytes, the muscle cells unique to the heart, but they do not appear to be organized in the same way and do not exhibit the typical contractile properties of heart muscle. Still, says Martin, "we've seen such good results in terms of function that we didn't care if they were myocytes or not."

As a result of that first study, completed last December (and still unpublished), Osiris quickly initiated a second round of trials in pigs—the same pigs that Martin visited that morning in May—and the results appear to confirm the initial tests. This second trial uses universal donor cells, rather than cells extracted from each pig's own marrow, that are injected immediately after the heart attack. Echocardiograms, including the ones Martin and his colleagues gathered during the May visit, have shown a statistically significant improvement in the pumping capacity of the heart. The company is now exploring the possibility of delivering these cells to precisely the right spot in a damaged heart through a catheter similar to the type used in angiograms or angioplasties.

The ultimate aim, Martin explains, is to manufacture "a universal [human] cell, cryopreserved, which could be in the emergency room of every hospital in the country, and used in emergent situations with heart attack patients." The hope is that initiating cellular therapy as soon as possible after a heart attack could significantly reduce permanent damage to the heart. Two days after Martin visited the pigs last May, Osiris officials met with U.S. Food and Drug Administration scientists, and they hope that, if all lingering regulatory and safety concerns can be satisfactorily resolved, a preliminary safety study of adult stem cells in humans with heart disease could feasibly be launched by the end of the year.

Another barnyard animal is providing further promising results for treating a condition that afflicts more than half of all Americans over the age of 65: osteoarthritis. At a farm north of Baltimore, Osiris scientists have been putting a dozen or so goats through their paces on treadmills. What's unusual about these goats is that each has sustained severe damage to one knee. To simulate conditions that commonly cause osteoarthritis, veterinary surgeons sever a ligament in the knee and remove the inner half of the meniscus, a resilient patch of cartilage that forms a cushioning pad between the thighbone and the larger of two bones that form the lower leg. The goats then spend several weeks on an exercise program using this wobbly, unstable joint—a regimen that literally rubs and erodes the remaining cartilage off the ends of the long bones. This activity creates a harrowingly accurate model of osteoarthritis.

Adult Stem Cells at Work

Some of the efforts under way to combat disease with stem cells derived from adult tissues

ORGANIZATION	SOURCE OF CELLS	CONDITION TARGETED	STAGE OF TESTING
Curis (Cambridge, MA)/ **Aegera** Therapeutics (Montréal, Québec)/ **McGill University**	Skin	Diabetes, neurological disorders, cardiovascular disorders	Research
Osiris Therapeutics (Baltimore, MD)	Bone marrow	Osteoarthritis	Animal studies
Osiris/Johns Hopkins University	Bone marrow	Heart attack	Animal studies
Osiris/nine clinical centers	Bone marrow	Blood supply recovery after cancer treatment	Human trials
Osiris/University of North Carolina	Bone marrow	Dental prosthesis	Human trials
StemCells (Palo Alto, CA)	Brain	Neurodegenerative diseases	Animal studies
StemCells	Liver	Hepatitis C and other liver diseases	Research
StemCells	Pancreas	Diabetes	Research
St. Jude's Children's Research Hospital (Memphis, TN)	Bone marrow	Osteogenesis imperfecta ("brittle-bone disease")	Human trials

Uncertain future: Irving Weissman warns that adult stem cells have not yet been characterized rigorously enough.

GRAVENOR

Osiris researchers have been using an ordinary syringe to inject approximately five to ten million adult mesenchymal stem cells into a little purse of tissue inside the knee, and the results have been encouraging. Although tested in only a handful of animals, the stem cells have not only restored the surgically removed meniscus but within 12 weeks have recarpeted the eroded, bony surface of the thigh and calf bones with new cartilage. "These cells respond to mechanical forces," Osiris's Barry explains, "and the fact that the animal is putting weight on the joint means the cells experience these dynamic forces. The second thing is that they respond to the local wound environment." Encouraged by the results in animal experiments, Osiris hopes to launch initial safety studies in humans before the end of the year.

One of the hottest areas of stem cell research would seem to be beyond the reach of adult stem cells: the brain. The problem, as Harvard Medical School researcher Evan Snyder bluntly puts it, is, "If you're talking about the brain, where would the adult stem cells come from?"

Fred Gage, a neuroscientist at the Salk Institute for Biological Studies in La Jolla, CA, whose group was the first to find adult neural stem cells in the mammalian brain, has offered a potential rejoinder. Earlier this year, Gage's team extracted what he calls adult neural progenitor cells from cadavers—leading to the possibility of harvesting the cells from fresh cadavers for medical use, much as hearts, livers and kidneys are harvested from accident victims for organ transplants.

In animal experiments, the researchers have shown that transplanted neural stem cells—much like the bone-marrow-derived stem cells in Mezey's experiments at the National Institute of Neurological Disorders and Stroke—can migrate to the zone in the brain where new neurological cells are formed and to areas of injury. The cells typically take on the shape and function of other cells in those spots. "Not only are new cells born, but they undergo synaptogenesis," or create the ability to connect with other nerve cells, Gage said at a meeting on stem cell biology at Cold Spring Harbor Laboratory last March.

One of the most surprising findings in the area, though—from Mezey's experiments and from a recent rat study conducted by Helen Blau's group at Stanford—is that it might not be necessary to start with stem cells taken from the brain, since stem cells from bone marrow may be able to repair neurological damage. "If we could learn what the signals are and learn how to make it more robust," Blau said at the Cold Spring Harbor meeting, "if we could get function [in these cells], and see if the cells migrate to damage, it might have great utility in the treatment of Parkinson's disease, stroke and trauma."

All those *if*s reflect that scientists are in the early stages of research in a field rife with uncertainty—and peril. The research community received a sobering reality check last March when neuroscientist Curt Freed and colleagues at the University of Colorado reported in the *New England Journal of Medicine* mixed results in a clinical trial in which embryonic neural cells (but not specifically stem cells) were implanted in the brains of patients with Parkinson's disease. Some of the patients experienced a small degree of improvement, but others developed severe and disabling side effects—constant, jerky motions—that were described as worse than the original symptoms of the disease. While the experiments did not specifically involve stem cells, the results served as a reminder that any cells, once implanted, can have not only unwanted but irreversible side effects.

The limited ability of adult stem cells to form many tissues, however, may be an advantage. "Adult stem cells have been used for years without side effects of that type," said Daniel Marshak, vice president of bioscience research and development for East Rutherford, NJ-based Cambrex, which provides services to stem cell scientists. "The adult stem cell has somewhat less capacity to do what it wants, but it may be somewhat more programmed to do the right thing."

Side effects and other clinical issues will need to be addressed as adult stem cell research progresses and more human trials are launched. Those studies will go a long way to eventually determining the real medical potential of these remarkable cells. But for now, the future of adult stem cells remains closely linked to the political and ethical debates surrounding their embryonic cousins.

Among many researchers, it has become almost politically incorrect to speak with unguarded enthusiasm about adult stem cell research—not because the research isn't exciting, but because such praise has inevitably provided ammunition to opponents of embryonic stem cell research. U.S. senator Sam Brownback of Kansas, for example, used recent results from Prockop's group at Tulane and Edwin M. Horwitz's group at St. Jude's Children's Research Hospital in Memphis, TN, to argue that adult stem cells are so potent and versatile that there's no need to destroy embryos to get their stem cells, and thus no need for the government to provide funding for embryonic-stem-cell research. But Prockop reflects the views of most scientists when he says, "We can learn from both groups of cells. We have too much to learn to stop any of this work."

There are, in fact, substantive scientific questions remaining to be answered before the relative merits of embryonic and adult stem cells can be determined. Some scientists claim embryonic stem cells are easier to grow in culture, and they are unquestionably capable of more cellular fates, but they also pose a small but theoretical risk of developing into cancerous tissues. Adult stem cells may not be as potent as embryonic stem cells, but preliminary clinical results suggest they are safe in humans. Yet they have many academic critics. Stanford biologist Irving Weissman argues that, almost without exception, adult cells have not been characterized rigorously enough, and he dismisses the politicians and religious figures who tout the virtues of adult stem cells, saying, "Those who have made the claim that human adult stem cells can do everything and anything that we want seem to know something that the experts don't know."

Nonetheless, virtually all the researchers who've laid their hands on adult and embryonic stem cells see them ushering in a new kind of medicine in the 21st century, where the healing wisdom of these powerful biological agents provides a kind of in situ doctoring, where repair and regeneration are startlingly real possibilities, where the drugstore of the future is as likely to dispense bags of cells as bottles of pills. The question, as much political as scientific, is how quickly we are going to get there.

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THE INNOVATORS

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TECHNOLOGY REVIEW

A SMARTER WEB

How do you endow the Internet's chaotic pile of bits with a structure that makes information easier to find and use? It's all a matter of semantics.

BY MARK FRAUENFELDER

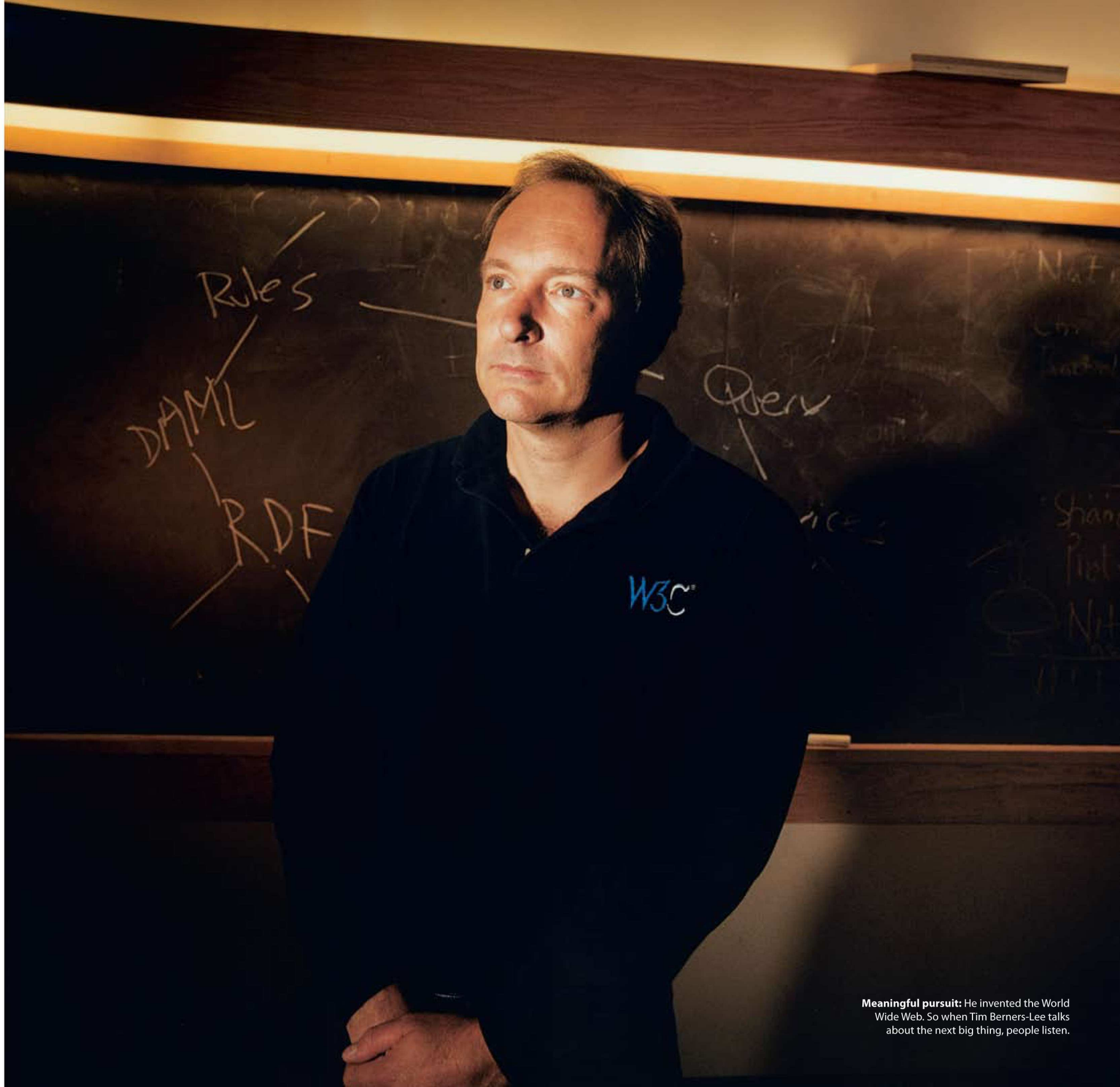
Photographs by Patricia McDonough

Tim Berners-Lee must feel like he's in a time warp. In the early 1990s, he spent a frustrating year trying to get people to grasp the power and beauty of his idea for a scheme known as an Internet hypertext system, to which he gave the beguiling name the World Wide Web. But since the Web didn't yet exist, most people couldn't imagine the implications of what he was talking about. Berners-Lee persevered, and with the help of the few people who shared his vision, his invention became the fastest-growing media distribution system in history.

A decade later, Berners-Lee is struggling with the same problem—only this time, he's trying to articulate his dream of a Semantic Web. The idea is to weave a Web that not only links documents to each other but also recognizes the meaning of the information in those documents—a task that people can ordinarily do quite well but is a tall order for computers, which can't tell if "head" means the leader of an organization or the thing on top of a body. "The Semantic Web is really data that is processable by machine," says Berners-Lee, who is director of the MIT-based World Wide Web Consortium. "That's what the fuss is about."

Today's World Wide Web is fundamentally a publishing medium—a place to store and share images and text. Adding semantics will radically change the nature of the Web—from a place where information is merely displayed to one where it is interpreted, exchanged and processed. Semantic-enabled search agents will be able to collect machine-readable data from diverse sources, process it and infer new facts. Programs that weren't made to be compatible with each other will share previously unmixable data. In other words, the ultimate goal of the Semantic Web is to give users near omniscience over the vast resources of the Internet, turning the millions of existing database islands into a single gigantic database Pangea.

To compare the Semantic Web with today's Web, Berners-Lee—an intense person who speaks in low-volume bursts—offers the following scenario: Imagine registering for a conference online.



Meaningful pursuit: He invented the World Wide Web. So when Tim Berners-Lee talks about the next big thing, people listen.

The conference Web site lists the event time, date and location, along with information about the nearest airport and a hotel that offers attendees a discount. With today's Web, you have to first check to make sure your schedule is clear, and if it is you have to cut and paste the time and date into your calendar program. Then you need to make flight and hotel arrangements, either by calling reservations desks, or by going to their Web sites.

Many feel it can't be done. Even though things are heating up in research labs, the Semantic Web as envisioned by Berners-Lee is hampered by social and technical challenges that some critics say may never be solved. But that's not stopping the World Wide Web Consortium and other organizations from trying. The U.S. Defense Advanced Research Projects Agency (DARPA) and commercial enterprises such as Network Inference in Manchester, England, are already developing tools for building the Semantic Web infrastructure—as well as applications for using it. And according to Berners-Lee, with growing numbers of people beginning to grasp how the Semantic Web will "allow more and more sophisticated agents to do things on their behalf," we'll soon see some glimmers of what could be in store.

EVEN IF BERNERS-LEE AND HIS COHORTS MEET THE TECHNICAL CHALLENGES, THAT WON'T BE ENOUGH FOR THE SEMANTIC WEB TO CLICK INTO PLACE. THERE IS A BIG QUESTION WHETHER PEOPLE WILL THINK THE BENEFITS ARE WORTH THE EXTRA EFFORT.

"There's no way you can just say, 'I want to go to that event,'" explains Berners-Lee, "because the semantics of which bit is the date and which bit is the time has been lost." But on the Semantic Web, he asserts, those bits will be labeled; the software on your computer will recognize those labels and automatically book your flight to the conference and reserve a hotel room with the click of a button.

The Semantic Web will also be a richer, more customizable Web. Imagine running your cursor over the name of the hotel and being informed that 15 percent of the people who've voted on its quality say it's excellent. If you happen to know that the hotel is a dump, you can instruct your browser to assign those people a trust level of zero. (The polling information would be saved on a third-party "annotation server" that your Web browser accessed automatically.) By assigning high levels of trust to people who match your tastes and interests, and "bozo-filtering" the people who don't, *the* Web will start looking more like *your* Web.

It's an enormous undertaking. The first step is to establish standards that allow users to add explicit descriptive tags, or metadata, to Web content—making it easy to pinpoint exactly what you're looking for. Next comes developing methods that enable different programs to relate and share metadata from different Web sites. After that, people can begin crafting additional features, like applications that infer additional facts from the ones they're given. As a result, searches will be more accurate and thorough, data entry will be streamlined and the truthfulness of information will be easier to verify. At least that's the goal.

Untangling the Semantic Web

In his crowded office on the third floor of MIT's Laboratory for Computer Science building, research scientist Eric Miller doesn't seem bothered by the pounding and grinding noises coming from heavy equipment on the construction site next door. As the head of the Semantic Web project, the friendly and energetic Miller is too enthralled with his new job to notice. "I'm the luckiest guy alive," he says. "I get paid for what I'd do for free."

Berners-Lee tapped Miller to head up the consortium's Semantic Web Activity because of Miller's involvement in Web-based knowledge management projects and his ability to enthusiastically articulate the concepts behind the Semantic Web. Standing next to a whiteboard covered in diagrams of metadata in action, Miller explains that the fundamental idea behind the Semantic Web is to make the Internet more useful to people by making the information floating all over the Web more easily manipulated by computers.

Today, by contrast, most content is formatted for human consumption. When you read a news article online, for instance, you can easily pick out the headline, byline, dateline, photo credit and so on. But unless these things are explicitly labeled, a computer has no idea what they are. It simply sees a bunch of text. In the Semantic Web, a news story will be marked with labels that describe its various parts, making it easy, among other things, for a search engine to find articles written *by* Jimmy Carter and not stories written *about* him.

That's not possible today, at least not on a global scale. The formatting tags used to create Web pages are part of the hypertext markup language (HTML), and they describe only what a Web page's information looks like (boldface, small, large, underlined, etc.). The Semantic Web would go beyond cosmetics by including tags that also describe what the information *is*: tags would label text as designating, for instance, subject, author, street address, price or shipping charge. These descriptive tags are the metadata—the data about the data. Metadata is not a new concept, nor one restricted to the Internet. A library's card catalogue—with its records describing a book's title, author, subject, year and location on the shelves—is metadata.

The Web made it trivially easy to exchange documents between previously incompatible computers (a few of today's Web users may recall the headaches of the 1980s, when computers from different makers were electronic islands). The Semantic Web will take this a step further, making it possible for computers to exchange particular pieces of information from within documents.

Beyond Metadata

You can't have a Semantic Web without metadata, but metadata alone won't suffice. The metadata in Web pages will have to be linked to special documents that define metadata terms and the relationships between the terms. These sets of shared concepts and their interconnections are called "ontologies."

Say, for example, that you've made a Web page listing the members of a faculty. You would tag the names of the different members with metadata terms such as "chair," "associate professor," "professor" and so on. Then you'd link the page to an ontology—one that you created yourself

Forward. The last several weeks have been a time of tragedy, but also of courage and hope. Our thoughts and prayers are with all those affected by the events of September 11th. Of the victims of Flight 11, Teradyne employee Peter Hashem was lost to his wife and two children, as well as his extended family, friends and coworkers. We grieve the loss of Peter, and we realize his family is one of thousands that will need our help. Together we can, and we will, move forward. Teradyne.

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or one that someone else has already made—that defines educational job positions and how they relate to each other. An appropriate ontology would in this case define a chair as a person, not a thing you sit on, and it would indicate that a chair is the most senior position in a department.

By defining the relationships between terms, ontologies can then be used by applications to infer new facts. Suppose you have created a Web page that teaches schoolchildren about condors, and have added metadata to the content. You could link to an ontology (or more likely, several ontologies) that define the various terms and their relationships: "California condor is a type of condor from California." "Condor is a member of the raptor family." "All raptors are carnivores." "California is a state in the United States." "Carnivores are meat eaters." By using both metadata and ontologies, a search engine or other software agent could find your condor site based on a search request for "carnivores in the U.S."—even if your site made no mention of carnivores or the United States.

Because ontology development is a big undertaking, it's likely that site creators will link to third-party ontologies. Some will be free, others will be sold or licensed. One issue that will have to be confronted: just as with dictionaries and atlases, political and cultural bias will creep into ontologies. A geography-based ontology maintained by the Chinese government, for instance, would probably not define Taiwan as a "country."

But that hardly impedes the vision. As the World Wide Web Consortium continues to develop standards and technologies for the Semantic Web, hundreds of organizations, companies and individuals are contributing to the effort by creating tools, languages and ontologies.

One major contributor is DARPA—the folks responsible for a great deal of the technology behind the Internet *(see "DARPA's Disruptive Technologies," TR October 2001)*. These days, DARPA is contributing tens of millions of dollars to the Web consortium's Semantic Web project and has developed a semantic language for the U.S. Department of Defense called DARPA Agent Markup Language that allows users to add metadata to Web documents and relate it to ontologies. University of Maryland computer science professor Jim Hendler—who was until August manager of the DARPA program—has been working closely with Berners-Lee and Miller to ensure consistency with the consortium's efforts. Last December, Hendler announced the creation of a language that combines the DARPA Agent Markup Language's capabilities with an ontology language, developed in Europe, called OIL (which stands for both Ontology Inference Layer and Ontology Interchange Language).

A developer of this new language, University of Manchester lecturer Ian Horrocks, also advises the World Wide Web Consortium on the Semantic Web. In January, he cofounded a company called Network Inference to develop technology that uses ontologies and automated inference to give Semantic Web capabilities to existing relational databases and large Web sites. Recently, an Isle of Man-based data services company called PDMS began using Network Inference's technology to add Semantic Web capabilities to corporate databases. Dozens of other companies, from Hewlett-Packard to Nokia, are contributing to Semantic Web development *(see "Spinning the Semantic Web," below)*.

Too Much, Too Late?

Miller believes the seamless flow and integration of information resulting from these moves will make it possible to process knowledge in a way "that solves problems, brings people closer and spurs on new ideas that never could happen before." Others, though, are not so optimistic about the Semantic Web. "It's rather ambitious," says R. V. Guha, who led development of the Web consortium's Resource Description Framework efforts in the late 1990s. (This framework is an essential tool for describing and sharing metadata.) "It would be nice if such things existed," he says, "but there are some really hard research problems that need to be solved first."

One issue concerns inference. The time it takes a computer to draw new conclusions from data, metadata and ontologies on the Web increases rapidly as rules are added to a system. Inference falls into the same category as the classic "traveling-salesman problem" of planning the shortest route through a number of cities. It's not hard to figure out the best of all possible routes when you're dealing with just a very few locations. But when you get up to only 15 cities, there are more than 43 billion possible routes. The same kind of runaway situation exists for inference, where brute-force searches for answers could lead to time-wasting paradoxes or contradictions.

AS THE CONSORTIUM DEVELOPS TECHNOLOGIES FOR THE SEMANTIC WEB, HUNDREDS OF ORGANIZATIONS, COMPANIES AND INDIVIDUALS ARE CONTRIBUTING TO THE EFFORT.

Spinning the Semantic Web

A sampling of companies developing tools and applications for the Semantic Web

COMPANY	FOCUS
Aidministrator Nederland (Amersfoort, the Netherlands)	Software to classify sites based on content and relationships
CognIT (Halden, Norway)	Software to share information among different applications
Hewlett-Packard (Palo Alto, CA)	Java-based tools to create and maintain metadata
Intellidimension (Windsor, VT)	Development of databases with semantic properties
Invention Machine (Boston, MA)	Semantic searching tools
Network Inference (Isle of Man)	Software to create ontologies and inference engines
Nokia (Espoo, Finland)	Markup and ontology languages
Ontoprise (Karlsruhe, Germany)	Ontology-editing and inference software
Taalee (Athens, GA)	Software to automatically generate semantic metadata for searching textual and audiovisual content

The whole world owes America a huge debt of gratitude for the willingness and determination of U.S. citizens to repeatedly risk their lives to ensure that freedom prevails. As I watched the televised opening of the New York Stock Exchange last Monday, as I saw the heroic firemen and policemen ring the opening bell, I was deeply moved by the unbroken power, strength and determination of this great country. One thing is clear. Each of us – in our own way – must work to ensure that the good, the right and the just will prevail in the end.

Excerpts from address by Dr. Heinrich v. Pierer, recipient of the Appeal of Conscience Award, Monday, September 24, 2001. Dr. v. Pierer is President and Chief Executive Officer of Siemens AG.

Founded in 1965, the Appeal of Conscience Foundation has worked on behalf of religious freedom and human rights throughout the world. This interfaith coalition of business and religious leaders promotes mutual understanding, peace and tolerance. The Foundation believes that freedom, democracy and human rights are the fundamental values that give nations of the world their best hope for peace, security and shared prosperity.

If you would like to read Dr. v. Pierer's speech in its entirety, visit www.siemens-usa.com
To learn more about the Appeal of Conscience Foundation, visit www.appealofconscience.org

And even if Berners-Lee and his cohorts meet the technical challenges, that won't be enough for the Semantic Web to click into place. There is a big question as to whether people will think the benefits are worth the extra effort of adding metadata to their content in the first place. One reason the Web became so wildly successful, after all, was its sublime ease of creation.

"The Web today is the simplest, most primitive form of hypertext," says former Sun Microsystems Distinguished Engineer Jakob Nielsen, cofounder of the Nielsen Norman Group, a Web design firm in Fremont, CA. "And that's why it was so easy to implement; that's why everybody could…start putting up their own Web pages; that's why the Web is so big." However, while most people may be comfortable doing simplistic editing, such as marking a text as "bold," Nielsen points out, "They cannot do semantic editing, where they say, 'This is the author's name,' or 'This is the name of people I'm quoting.'"

Of course, such pessimism may be ignoring recent history. Not so long ago, the notion of millions of people learning to write HTML code seemed far-fetched—yet that's exactly what happened. Still, the hurdle of creating a Semantic Web will be higher. People can use HTML any way they want. They commonly use tables for nontabular purposes, for instance, and slap on the "subhead" tag merely to apply boldface. These kluges and shortcuts usually have only cosmetic consequences. But the same type of fudging—say, by employing "bibliography" tags to list a DVD collection—could make a page's metadata unusable.

The fact that metadata wasn't implemented right from the Web's start could also make it harder for the Semantic Web to gain acceptance. One particularly tough skeptic is Peter Merholz, cofounder of Adaptive Path, a San Francisco-based user experience consultancy. "This stuff has to be baked in from the beginning," says Merholz, who calls the Semantic Web "an interesting academic pursuit" with little bearing on society. "The Semantic Web is getting a lot of hype simply because Tim Berners-Lee—the inventor of the World Wide Web—is so interested in it," he says. "If it were just some schmuck at some university in Indiana, nobody would care."

Initial Threads

Even Berners-Lee admits that the path to the Semantic Web may be a bit slower than that to the World Wide Web. "In a way we don't need to move too fast," he says, "because the theory people need to look at it to make sure we're not too crazy, and other people need to check out the ideas in practice before they're picked up and used too extensively."

When asked to peek into his crystal ball, the evangelist of exchangeable data predicts that some of the Semantic Web's first commercial applications will aim to integrate the different information systems that typically coexist in large organizations. (Wouldn't it be nice to take care of business at the motor vehicle department or hospital without having to fill out a half-dozen largely redundant forms? The Semantic Web can help here.)

And even though the Semantic Web still resides chiefly on the drawing board, you can see hints of its power on some existing Web sites. Consider Moreover Technologies' search engine that crawls thousands of news sites several times a day, making it a favorite for news junkies. Moreover's software agents have been programmed to look at the font tags (the HTML labels that tell Web browsers how large or small to make the text appear on the screen) to determine whether or not a particular page is a news story. If a Moreover agent finds a string of six to 18 words tagged as large type near the top of a page, it will assume it is a headline and place it in a database. Of course, since the agent is only making a guess, sometimes it selects a page that isn't news after all. So Moreover has to apply additional filtering to get rid of pages that don't contain articles.

That's still a far cry from the ultimate goal—but it's a good start. And even the Semantic Web champions don't pretend to grasp exactly where such steps will lead. After all, who predicted Amazon.com or eBay back when Berners-Lee turned on the switch of the world's first Web server in December 1990?

But the point is that people want more intelligence from the Web than they're getting—and a growing number of computer scientists share the twinkle in Berners-Lee's eye, and the feeling that the Semantic Web holds the answer. "It's great," says the inventor of the World Wide Web, "to have that grass-roots enthusiasm around again." TR

Maestro of metadata: Semantic Web project leader Eric Miller wants to link the Net's information islands into a database Pangea.

Security guard: Working in his home command post, consultant Jim Settle breaks into computer networks to keep bad guys out.

INFORMATION WARFARE

BREAKING INTO NETWORKS IS MORE THAN A JOYRIDE—IT'S THE COMING MISSION OF CRIMINALS, INDUSTRIAL SPIES AND TERRORISTS. CAN NEW SECURITY TECHNIQUES STOP THEM?

BY DAVID FREEDMAN
PHOTOGRAPHS BY ETHAN HILL

THE MIDDLE-AGED MAN—CALL HIM JOHN—PEERED AT THE NUMbers rolling across his computer monitor, which provided the only illumination in the cramped basement. One number, 307, caught his eye. Like the others, it designated a port, or gateway, between a certain corporation's computers and the outside world. John had just run a program on his PC that sent electronic probes throughout the corporation's network to find a complete list of these ports. Port 307 was "open"—any data coming through it could be displayed on John's screen. Would the information prove useful?

It did. Port 307 turned out to be where one network server sent bad passwords, along with the usernames of whoever typed them in. Network administrators had taken the trouble to hide legitimate passwords from prying eyes but hadn't worried about rejected passwords. John knew, however, that most failed passwords aren't wild guesses but rather are "fat-fingered," or typos. It was pretty easy to guess what "valentime3" was meant to be. Seconds later, John had logged onto the server. Three minutes after that he discovered a password file that listed one user's password as blank—a shortcut favored by systems administrators out to avoid having to type in a password hundreds of times daily. Now John had "root access," meaning the server recognized him as God. He whooped and called Jim Settle, former head of the FBI's computer crime squad and now CEO of Washington, DC-based security consultancy SST. "I'm in."

Settle congratulated him, hung up and called the chief information officer of the corporation whose network his man had just penetrated. "Guess who just took over your network?" asked Settle. The man was stunned—but grateful. After all, he had quietly retained Settle's services precisely to learn if his network was vulnerable. Now he knew. Before Settle and his crew finished, they would find dozens of other ways to take control.

Though Settle's break-in took place with the victim's blessing, it echoes tens of thousands of malicious invasions. Each year the Computer Security Institute, a San Francisco-based organization of computer security professionals, and the FBI survey computer security managers at large companies and government agencies. In this year's survey of 538 managers, 85 percent of these organizations suffered security breaches; most suffered financial loss as a result. The average reported loss: about $2 million.

IMAGINE THE COMPUTER-DRIVEN TARGETING DISPLAYS IN BOMBERS MISIDENTIFYING FRIENDLY INSTALLATIONS AS ENEMY POSITI

That probably offers an optimistic view of the problem's scope. Settle has been hired by more than 60 companies to "red team" their computer systems—that is, to test security by breaking in the way hackers would. Not only did his people gain intimate access to every system, but only one firm even detected a breach. Moreover, the problem's not just corporate: according to a review by the U.S. General Services Administration, outsiders broke into and temporarily controlled at least 155 computer systems at 32 federal agencies last year.

And that's not even the bad news. While computer network break-ins have long been almost exclusively the work of joyriding, bored teenagers, security and law-enforcement professionals believe the threat is about to shift from run-of-the-mill hackers toward professional criminals, industrial spies, hostile governments and terrorists. Eventually, say experts, computer attacks are likely to bankrupt companies, compromise U.S. security and perhaps even kill hundreds or thousands of citizens by disrupting computer control of anything from traffic signals to food supply transport. "These threats are real," says Jack Holleran, former technical director of the National Security Agency's National Computer Security Center and now an independent computer security consultant. "It's just a matter of when, and it will be sooner rather than later."

The rising stakes have touched off an escalating stream of network skirmishes between those determined to break into organizations' computers and those charged with protecting them. Right now, the bad guys are winning. "Internet security is a big mess," says Bill Cheswick, a chief scientist at Lumeta, a Somerset, NJ, computer-security software firm spun off from Lucent Technologies. "It gets discouraging sometimes." That sobering reality has sent Cheswick and other top computer scientists into their labs to come up with new weapons for the intensifying battle.

Electronic Pearl Harbor

THE HAVOC THAT CAN BE WREAKED ONLINE HAS BECOME almost limitless. Unless you're living deep in the woods on fish you catch, chances are almost every aspect of your life is mediated through computers, from your train ride into work (thanks to computer-controlled track switches) to paying bills to relaxing in front of the television (which gets its juice from a computerized electric power grid). A terrorist organization or hostile nation that wanted to disrupt life in the United States, or a thief who wanted to plunder a company, has an embarrassment of riches to choose from, notes Pat Lincoln, director of the Computer Science Laboratory at nonprofit research institute SRI International. Lincoln, whom U.S. officials have briefed on these concerns, notes that though the details are classified, the government is carefully watching several groups and nations for warnings of computer attacks. "If you're recruiting people to drive trucks that blow up, maybe next year you'll get someone to plant an Internet 'worm,'" says Lincoln.

Possible targets of terrorist or state-sponsored attacks include electric power grids, natural-gas pipelines, water supplies, dams, hospitals and a variety of other critical facilities that could be paralyzed by assaults on the right computers, possibly resulting in widespread suffering and even death. Holleran notes that 80 percent of the food transported by rail in the United States crosses either of two bridges over the Mississippi River; even a moderate computer-driven mishap near one of them could potentially cause shortages and skyrocketing food prices. Phone service could increasingly be at risk, too, thanks to plans to move most voice traffic onto the Internet, which is far less secure than conventional phone networks. Banks, stock exchanges, the U.S. Social Security Administration and the U.S. Postal Service are also vulnerable. An attack on any such crucial network would serve as what security experts call an "electronic Pearl Harbor."

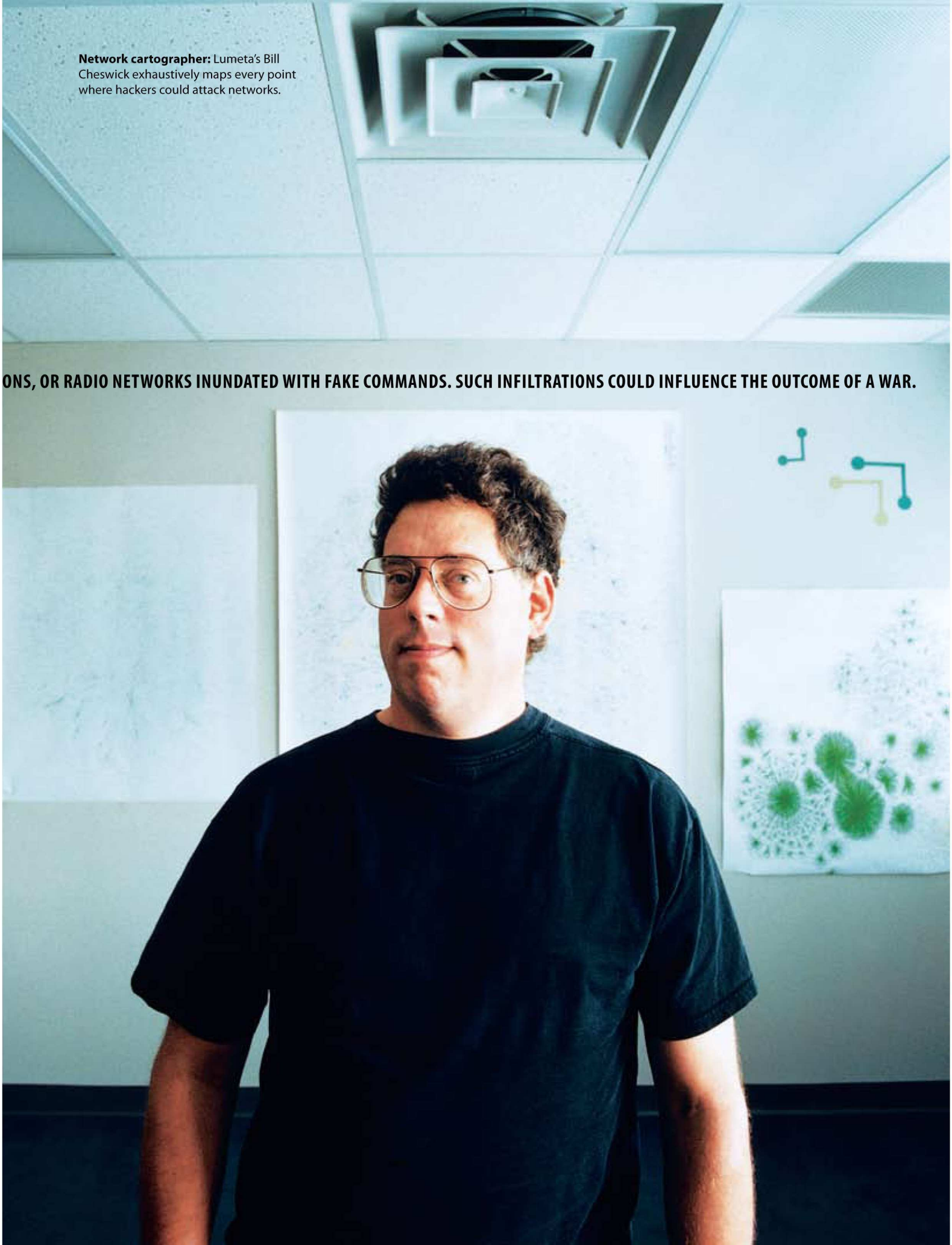
Access to, or a means to disrupt, military networks would be a special prize in this computer cold war. "A commercial site might be willing to put up with a certain amount of fraudulent traffic" that slows or temporarily halts service, says Robert Anderson, head of the information sciences group at nonprofit think tank the Rand Corporation. "But in a military system you'd be talking about lives being lost." Imagine, for example, the computer-driven targeting displays in tanks and bombers misidentifying friendly installations as enemy positions, or radio command networks being disrupted, or even inundated with fake commands. Such infiltrations could conceivably influence the outcome of a war. Uncle Sam is widely believed to have developed its own capabilities for attacking enemy computer systems, but because the United States tends to be far more computer dependent than its overseas counterparts, we have more to lose via information warfare, Anderson says.

Computer attacks could even become a force to reckon with in politics, notes AT&T Labs security expert Avi Rubin—at least if some communities follow through on plans to allow voting over the Internet. All a malicious agent would have to do is launch a mild attack that slowed down a vote-processing server enough to prevent a few percent of the ballots from getting through in a couple of districts. "It's the easiest type of attack one could possibly launch, and it could be enough to disrupt an election," says Rubin.

On the business side, the attacks are less theoretical. Citibank was ripped off in 1994 to the tune of $10 million by a Russian computer whiz, who transferred the funds to his and his accomplices' accounts. Most of the money was eventually recovered, but experts say there have probably been larger, more successful computer heists at other financial-services companies. Why haven't we heard about them? Because the companies

Network cartographer: Lumeta's Bill Cheswick exhaustively maps every point where hackers could attack networks.

ONS, OR RADIO NETWORKS INUNDATED WITH FAKE COMMANDS. SUCH INFILTRATIONS COULD INFLUENCE THE OUTCOME OF A WAR.



quietly bury the loss in the books as some other type of expense. "If someone breaks into a company's computers and gets $50 million, the company will feel there's nothing to gain by reporting it," says Jon David, a senior editor of the journal *Computers and Security* and a security manager at a large financial-services firm. "It just makes customers and stockholders nervous."

For a growing number of thieves, though, purloined corporate information—not money—is likely to become the currency of choice. R&D data, financial records, personnel files, details of upcoming deals—corporate servers are treasure troves of data that can be sold to competitors, speculators or anyone with a grudge. And of course, a few firms or their employees may stoop to direct computer-based espionage against competitors. Since hijacked information would typically be copied and not altered, companies might never know they've been hit. In a so-far-unique public case of industrial espionage allegedly carried out by computer, Moore Publishing, a Wilmington, DE, investigative firm, filed a $10 million lawsuit against Steptoe and Johnson, a well known Washington, DC, law firm. Settled in July 2000 for an undisclosed sum, the suit claimed that Steptoe and Johnson repeatedly broke into Moore computers, allegedly in revenge for Moore's having bought the rights to the "steptoejohnson.com" domain name (which it subsequently gave up).

Infinite Standoff

THE SECURITY WAR CAN SEEM LIKE AN INFINITE STANDOFF; for every new defense researchers devise, invaders develop countermeasures, leading to counter-countermeasures, and so on. Fortunately, defenders don't have to make it impossible to break into networks; they only have to make getting in so difficult, or so fraught with the risk of being tracked down, that the bad guys think twice.

Consider, for example, the most common means of breaking into a computer system: stealing passwords. Since employees often use a word or proper name as a password, would-be intruders can turn to any of several automated password-guessing programs freely available on the Web (try a search on "LOphtCrack," for example) to run through a dictionary full of guesses. "It just takes one user with a bad password to compromise a system," says Dorothy Denning, a computer scientist at Georgetown University.

To fight back, organizations can enlist software that automatically rejects passwords based on words or names and forces users to change their passwords regularly to limit potential damage. Even safer are security "tokens"—devices from keychains that plug into computers to small liquid-crystal displays—which make stolen passwords less valuable. Tokens like those made by Symantec and San Jose, CA-based Secure Computing dynamically generate a new password each time a user needs to log in; a version made by RSA Security of Bedford, MA, generates a new password every minute or so in synchronization with servers. But even these precautions won't stop highly motivated malicious agents. They can fast-talk employees out of passwords by posing as systems administrators over the phone or simply walk through the offices, where they can often spot passwords that are written down. And acquiring a token can be as simple as stealing a purse.

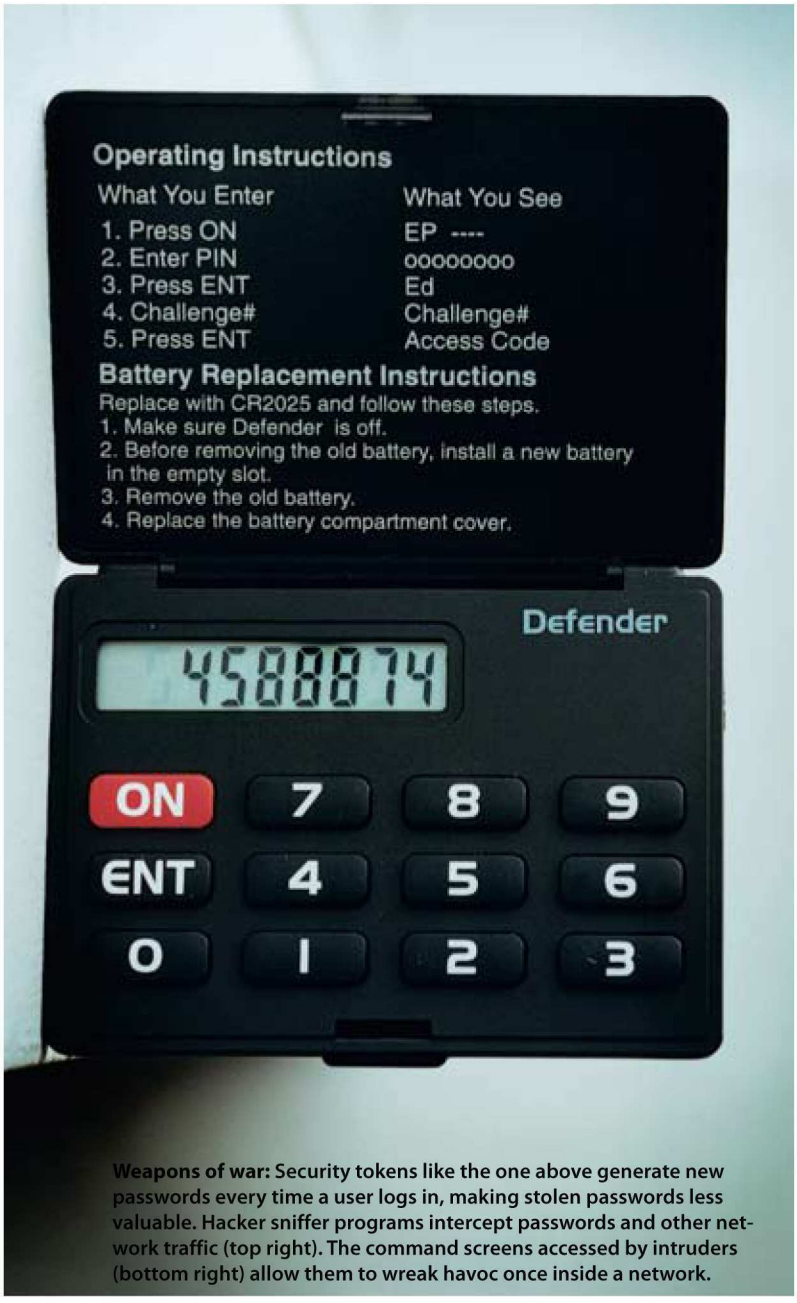
A growing number of companies and government agencies are also turning to smart cards to limit illicit entry into their systems. Smart cards have embedded computer chips containing code that identifies the holder. Passed through a reader that can be attached to any computer, the smart card authorizes the holder to use that computer to access the network: the network will reject commands from a computer that hasn't been presented with an authorized smart card. Smart cards can also contain the "keys" required to read or send encrypted data. Unlike encryption keys stored on a PC, keys encoded on a smart card can't be stolen via the network. Even tighter access control can be engineered by combining smart cards with "biometric signatures" like fingerprints or voiceprints. RSA Security, Luxembourg's Gemplus and the Datacard Group in Minnetonka, MN, are among the vendors already selling smart cards; Siemens offers smart cards tied to a fingerprint, and Domain Dynamics of Swindon, England, is prototyping cards encoded with voiceprints.

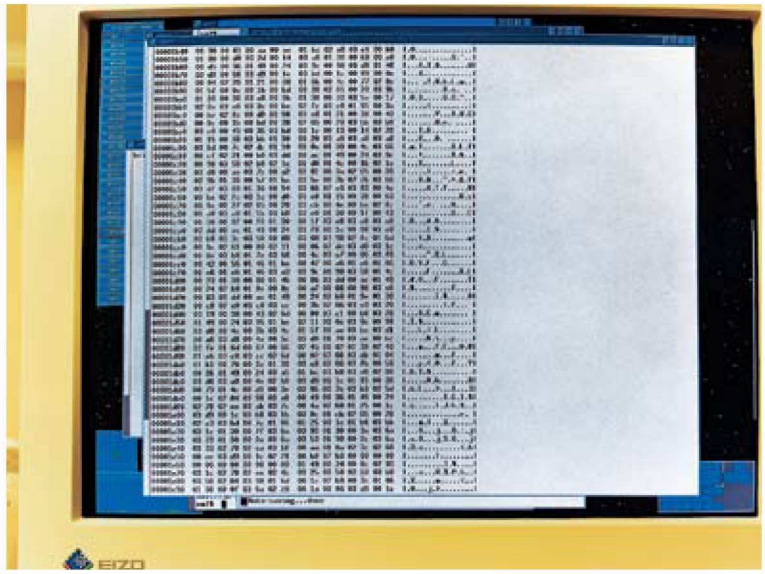
Of course, smart cards can be stolen, too, and though tamper-resistant, the code on embedded chips can in theory be cracked once a card falls into the wrong hands. One way around this weakness is to build the authorization chips into the innards of the computer itself. This way, bad guys must physically get their hands on an authorized computer to crack a network—a dicey proposition that even if successful isn't likely to go unnoticed for long. IBM, Intel, Hewlett-Packard, Microsoft and Compaq Computer founded the Trusted Computing Platform Alliance, now 170-plus members strong, to push for the development of such chips. The technology could be used in conjunction with smart cards and other security devices. "It puts a hardware barrier in front of a malicious software attack," says David Safford, manager of IBM Research's Global Security Analysis Laboratory. Safford estimates that in three to five years, every computer built will include the chips. IBM Research has also developed a tamper-proof device that can be installed in servers, similar to the chips endorsed by the Trusted Computing Platform Alliance.

COMPANIES OFTEN FIND OUT ABOUT VULNERABILITIES WHEN "WORMS" SPREAD THROUGHOUT THEIR NETWORKS. "IF YOUR NETWORI

Eventually, though, the chip has to talk to software, and some security experts peg that as the weak point of the Trusted Computing Platform Alliance's scheme. And once logged into a system, intruders can send commands that might coax the operating system—whether it's Unix, Microsoft Windows or Sun Solaris—into granting them systems administrator privileges. That typically includes the ability to examine server files, gain access to other servers, install "back doors" that allow easy future entry and cover their tracks by altering the system's logs.

Operating systems can be "tightened down" to prevent this sort of manipulation, but most systems administrators aren't familiar with the approximately 300 manual programming routines the procedure requires. Even if they are, malicious parties can exploit newly discovered holes (an average of 10 new Windows vulnerabilities, for example, circulate around the Web each month) unless systems administrators are unusually diligent about updating security features. "The machines get worse





Weapons of war: Security tokens like the one above generate new passwords every time a user logs in, making stolen passwords less valuable. Hacker sniffer programs intercept passwords and other network traffic (top right). The command screens accessed by intruders (bottom right) allow them to wreak havoc once inside a network.

< IS TIGHT, YOU SHOULD NEVER SEE ANYTHING LIKE CODE RED INSIDE. BUT IT RAN THROUGH ALL KINDS OF ORGANIZATIONS."

just sitting there," notes Dan Farmer, a security consultant who has worked extensively for Sun Microsystems.

A terrorist or industrial spy doesn't have to be proficient in the nuts and bolts of security hole exploitation to capitalize on these weaknesses. Software penetration "tool kits" that automate the process of invading and taking over a system can be downloaded from thousands of sites on the Web.

To help combat marauders who exploit such server vulnerabilities, systems administrators can employ intrusion detection software, such as Cybercop from Santa Clara, CA-based Network Associates, Cisco Systems' Secure IDS and SRI International's Emerald. These systems monitor network traffic looking for sequences of commands specifically associated with malicious attacks, as well as out-of-the-ordinary command sequences or data traffic. When the software spots something unusual, it notifies the systems administrator, who can then decide whether to shut the questionable traffic down.

But some attacks will be new and subtle enough to avoid detection. Or more commonly, invasions may be detected but ignored. Routine hackers and even inept legitimate users so frequently trigger current intrusion detection systems that many systems administrators disregard the alarms—or turn them off. Many of the companies Jim Settle's team penetrated were running high-end intrusion detection software costing $100,000 or more but for one reason or another didn't recognize the attack.

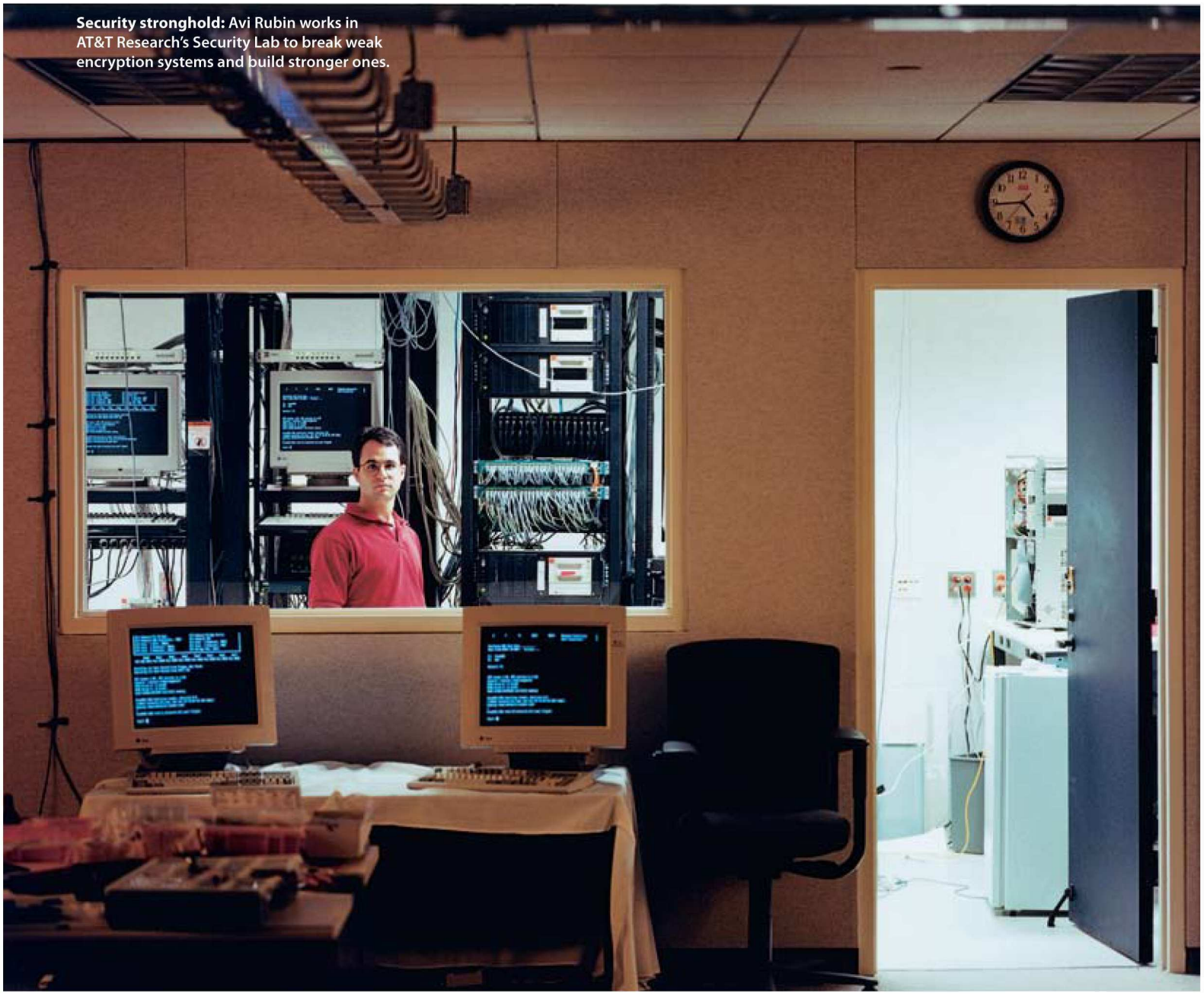
To counteract these glitches, researchers at Sandia National Laboratories, Network Associates and Cisco are working on intrusion detection systems that do a better job of differentiating false alarms and amateurish attacks from serious invasions. Some systems under development will even be able to analyze activity across a network to distinguish isolated attacks from the sort of massive, coordinated assaults that tend to be more damaging, says Fred Cohen, a security consultant and Livermore, CA-based Sandia researcher who coined the term "computer virus." Future

intrusion detection systems, he notes, will also make the network "self-coordinating": when a particular server is under attack, the network will place similar servers on high alert, or even shut them down, under the assumption that the attacker will attempt to exploit related vulnerabilities. Cohen has been working on ways to allow intrusion detection systems to recognize "slow attacks," an especially subtle and hard-to-spot technique in which an attack is purposely spread out over hours or even days to avoid triggering conventional alarms. "Most organizations have been ignoring that problem, because they have their hands full just recognizing attacks that occur in real time," he says.

Cohen is also among those working on another method to defend servers: so-called deception techniques. These involve setting the network up not merely to resist intruders but also to confuse and mislead them—preventing them from causing damage and making it easier to monitor their activities. For example, an intruder will normally use software to scan a network for open ports, typically resulting in a list of 30 or so gateways that can be explored for vulnerabilities. One deception technique is to have the network automatically reply to a port scan with a list of a million or more ports—far more than even the most motivated agent is likely to sift through looking for weaknesses. Organizations that want to go all out can even set up entire databases of phony information that are made available to anyone trying to improperly access the system.

Cohen notes that some security professionals have shied away from deception techniques out of concern that legitimate users will be fooled or inconvenienced, but he disagrees. "We've been experimenting with the techniques for four years on our networks, and we haven't seen one case where a user wasted time because of them, or as far as we know, one case where an attacker got to real data," he says. Cohen currently gives away some deception software on his Web site, and

"IF THE FBI IS WHERE OUR EXPERTISE LIES, WE'RE IN TROUBLE"— THEY'RE ILL EQUIPPED TO DEAL WITH COMPUTER CRIME AND TERRO



Security stronghold: Avi Rubin works in AT&T Research's Security Lab to break weak encryption systems and build stronger ones.

security firm Recourse Technologies of Redwood City, CA, sells a product called ManTrap, probably the most sophisticated deception system available commercially. But Cohen says more advanced systems are generally built in-house because they require a great deal of customization and maintenance.

In an effort to identify network vulnerabilities before invaders exploit them, companies can run software designed to ferret out and flag flaws. For example, Bill Cheswick's group at Lumeta sends a barrage of specially tagged packets of data from inside an organization's network to servers outside the network, and vice versa. The software then points out any network servers that let traffic move through in both directions. Such "leaky" servers represent an easy way in for intruders—and for malicious software like the Code Red worm that infected servers worldwide last summer. "The way companies usually find out about leaky servers is when a worm like Code Red spreads throughout the network," notes Cheswick. "If your network is tight, you should never see anything like Code Red inside. But it ran through all kinds of organizations."

threat turns out to be," says Lockheed Martin's Peterson.

To guard against threats that pros haven't even imagined yet, Peterson advocates a different sort of defense: rethinking the basic architecture of organizational networks. Conventional corporate network architecture, he says, affords employees fairly open access to internal databases, while attempting to place generally ineffective restrictions on connections to the outside world. Under that scheme, he says, a malicious agent need only gain access to an employee's computer in order to get into the databases.

Under the plan Peterson supports, users would have relatively open access to the outside world, while databases and other files are placed under severe and closely monitored restrictions. That way, an invader could take over Internet servers and employees' computers but still couldn't gain access to the databases and files—because nobody gets free access. "You have to be willing to reverse your thinking," Peterson says. "Not many people are."

)RISM. INVADING HACKERS CAN MORE OR LESS OPERATE WITHOUT FEAR OF BEING TRACKED DOWN, EVEN IF THEY'RE DETECTED.

Cybercrime's Next Frontier

EVEN WHEN SECURITY PROFESSIONALS MANAGE TO DEFEND existing networks, the ever increasing demand for more access by legitimate users creates new vulnerabilities. Take the explosion in wireless data networks, which allow an organization's employees to exchange messages and other data while wandering around with laptops and other devices. These networks provide malicious agents with "the next great frontier" for cybercrime, says Padgett Peterson, a Lockheed Martin security expert. The Internet is lousy with instructions for breaking into cell phones, pagers and personal digital assistants like the Palm. Intruders can also try "war-driving," which involves cruising the roads around corporate or government strongholds with equipment that intercepts wireless data transmissions—no passwords needed.

In an attempt to defeat such drive-by hacking, many wireless networks incorporate the popular Wired Equivalent Privacy protocol, which scrambles all data sent over the network. Unfortunately, AT&T researchers led by Avi Rubin and guided by theoretical work published by researchers at Cisco and the Weizmann Institute in Israel cracked the scheme in August, essentially rendering it useless. Rubin suggests replacing the approach with a technique compatible with the new (and so far impenetrable) Advanced Encryption Standard expected to be adopted by government agencies by year's end. But this won't be much consolation to organizations that have already invested millions of dollars in setting up their wireless networks. "When the new standard comes out, all the wireless PC cards and base stations will have to be replaced," says Rubin.

But no matter how successfully such technologies fend off existing threats, no end to the security wars is in sight. That's because experts can't predict perfectly what tricks criminals, spies and saboteurs will come up with next to turn our reliance on computers against us. "I'm always surprised by what the next

There's another weakness to address: law enforcement's limited ability to respond to computer security threats. Despite increasing security efforts in both the private and public sectors, sophisticated invaders can more or less operate without fear of being tracked down, even if they are detected. "Law enforcement and systems administrators are always behind the curve," says Settle. Experts agree that the FBI, which bears much of the federal responsibility for responding to computer attacks, is woefully ill equipped to deal with computer crime and terrorism. "If that's where our expertise lies, we're in trouble," says *Computers and Security* editor David. That's another reason most companies don't bother to report break-ins when they manage to detect them. In the Computer Security Institute and FBI survey, only 36 percent of the companies that admitted to being hit said they reported the crime to law enforcement.

It may be, says security consultant Farmer, that the only reason we haven't been victimized by a much more intense barrage of computer assaults is that most professional criminals and terrorists still perceive conventional physical attacks like armed robbery and bombings as providing more reliable payoffs. "That will change as we move our critical infrastructures online," he asserts.

In the end, the solution may be to rethink what the Internet is good for, as Lockheed Martin's Peterson suggests. Just as savvy travelers know not to pack irreplaceable possessions in a checked suitcase or walk in an urban park after dark, so organizations and individual users will recognize that highly sensitive data shouldn't be sitting on easily accessed servers. "Security probably won't improve in a technical sense," says Farmer. "Only in a social sense."

As for less sensitive information, well, organizations may need to accept the notion that the advantages of keeping it accessible outweigh the pain of occasionally having it swiped. Consider it a cost of doing business in a wired world—or to put it another way, an acceptable casualty of electronic war.

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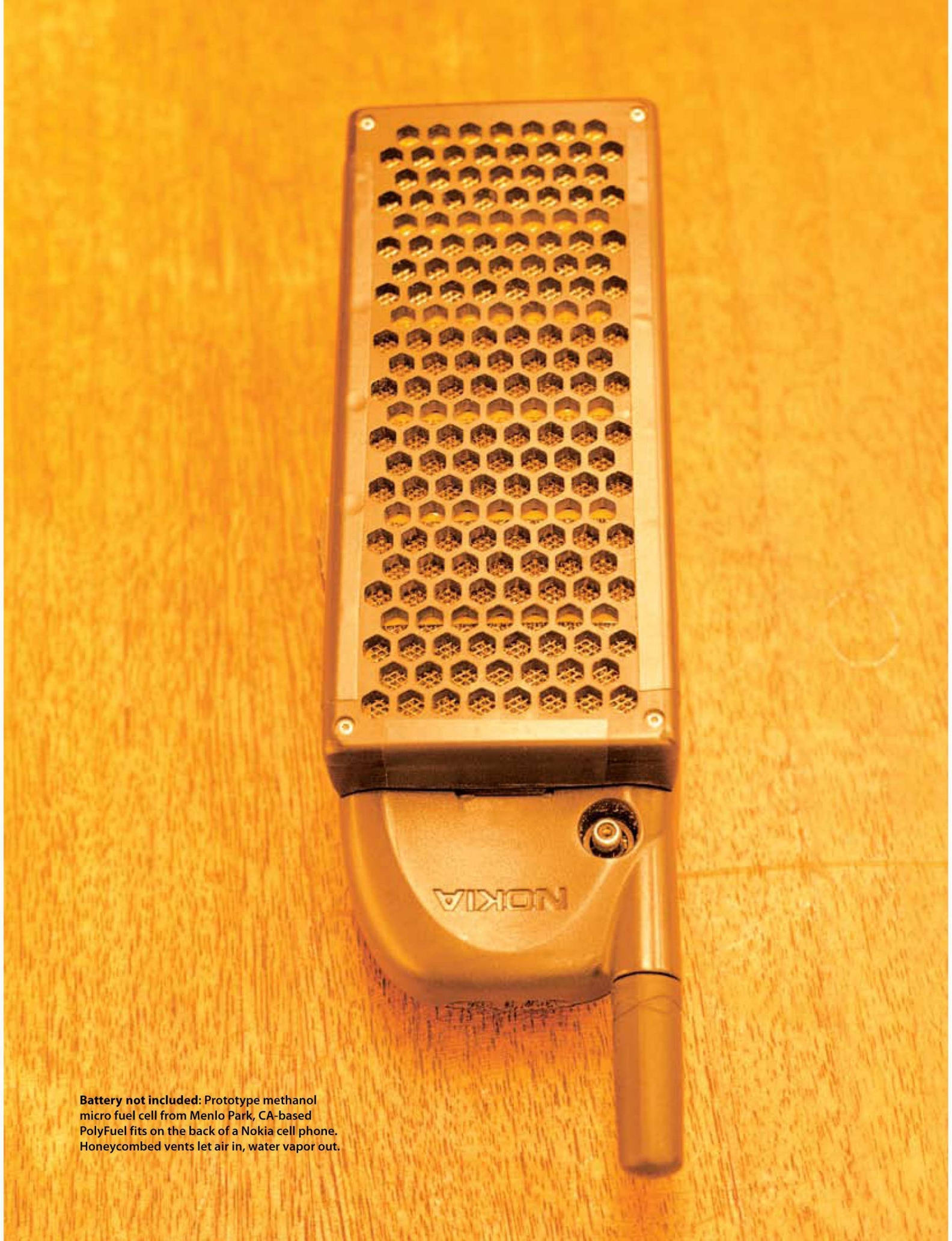
A FUEL CELL IN YOUR PHONE

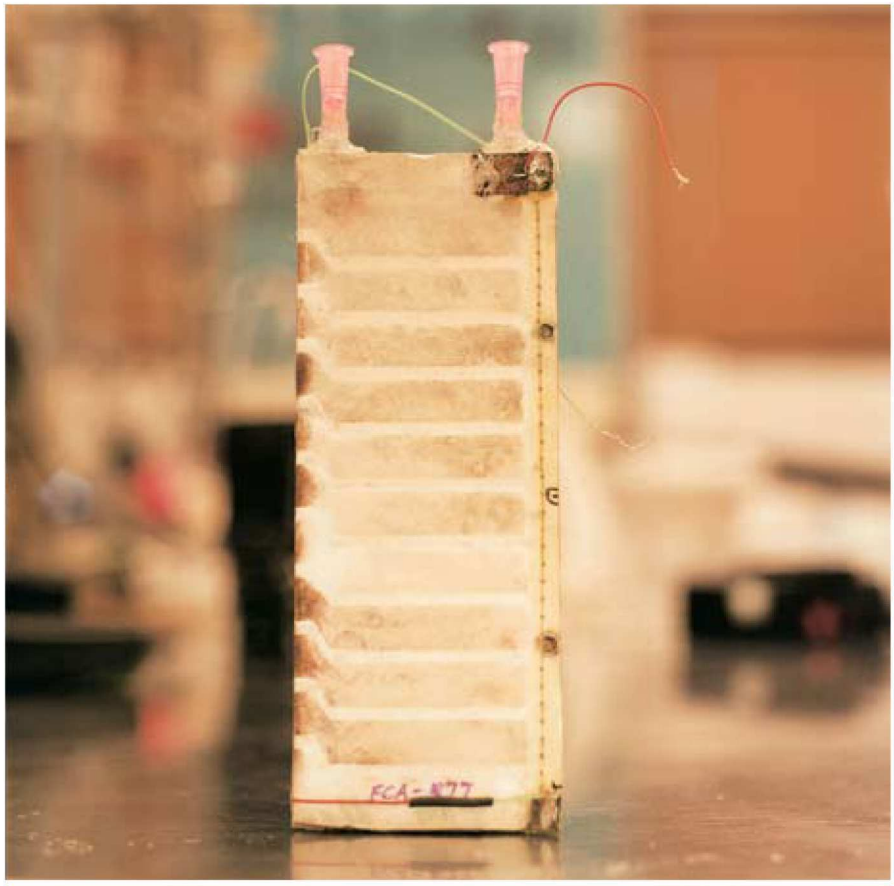
TIRED OF SHORT-LIVED BATTERIES? METHANOL-POWERED MICRO FUEL CELLS ARE RACING TOWARD MARKET, PROMISING UP TO 20 HOURS OF CELL-PHONE TALK TIME.

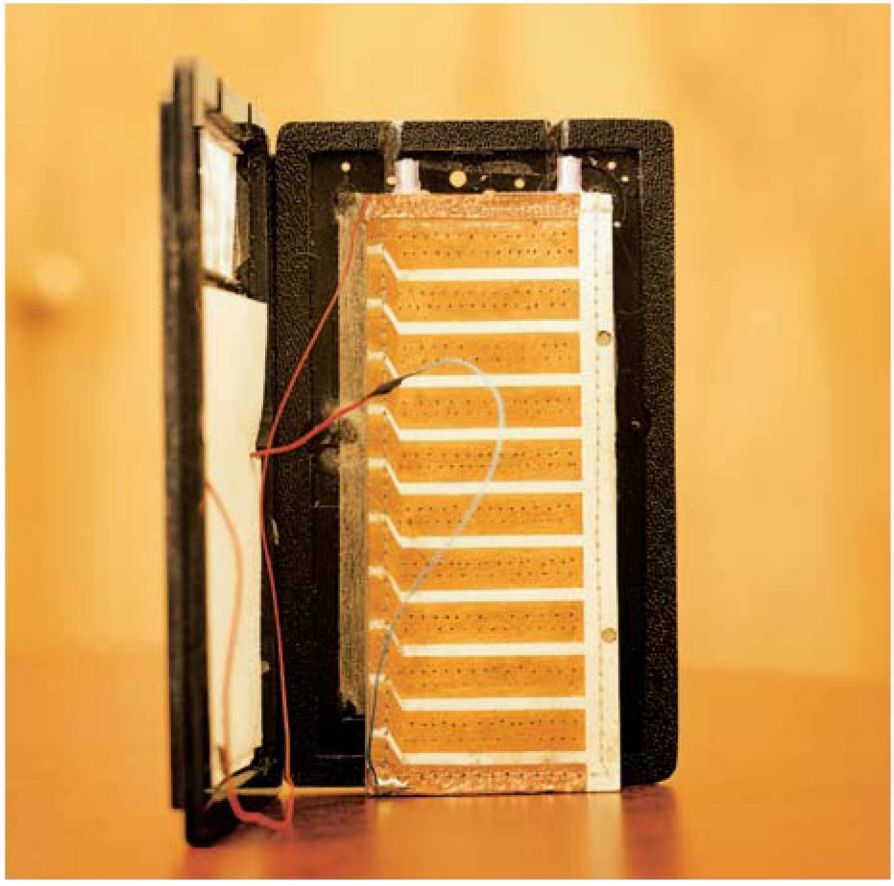
In a Los Alamos, NM, industrial park not far from the laboratory birthplace of the atomic bomb, Robert Hockaday sits in the cluttered lab of his startup company Manhattan Scientifics, holding a business-card-sized patch of clear plastic. Closer inspection shows a circuit-board-like pattern of black platinum and ruthenium printed on either side. The contraption is the innards of a five-centimeter-by-13-centimeter power plant that generates its own electricity using methanol as fuel. It may not look like much at first glance, but it's one member of a new class of tiny power packs that is ready to explode onto the market—and that just might annihilate one of the world's most ubiquitous technologies, the battery.

BY DAVID VOSS | PHOTOGRAPHS BY TIMOTHY ARCHIBALD



Battery not included: Prototype methanol micro fuel cell from Menlo Park, CA-based PolyFuel fits on the back of a Nokia cell phone. Honeycombed vents let air in, water vapor out.





All charged up: Just five centimeters by 13 centimeters, a prototype fuel-cell battery charger made by Manhattan Scientifics (top) produces 80 milliwatts. Its 10 fuel cell segments have gold-plated electrodes sandwiched between white plastic insulators. A methanol/water fuel mixture is injected through the pink tubes on top. A second prototype (bottom) fits inside a calculator.

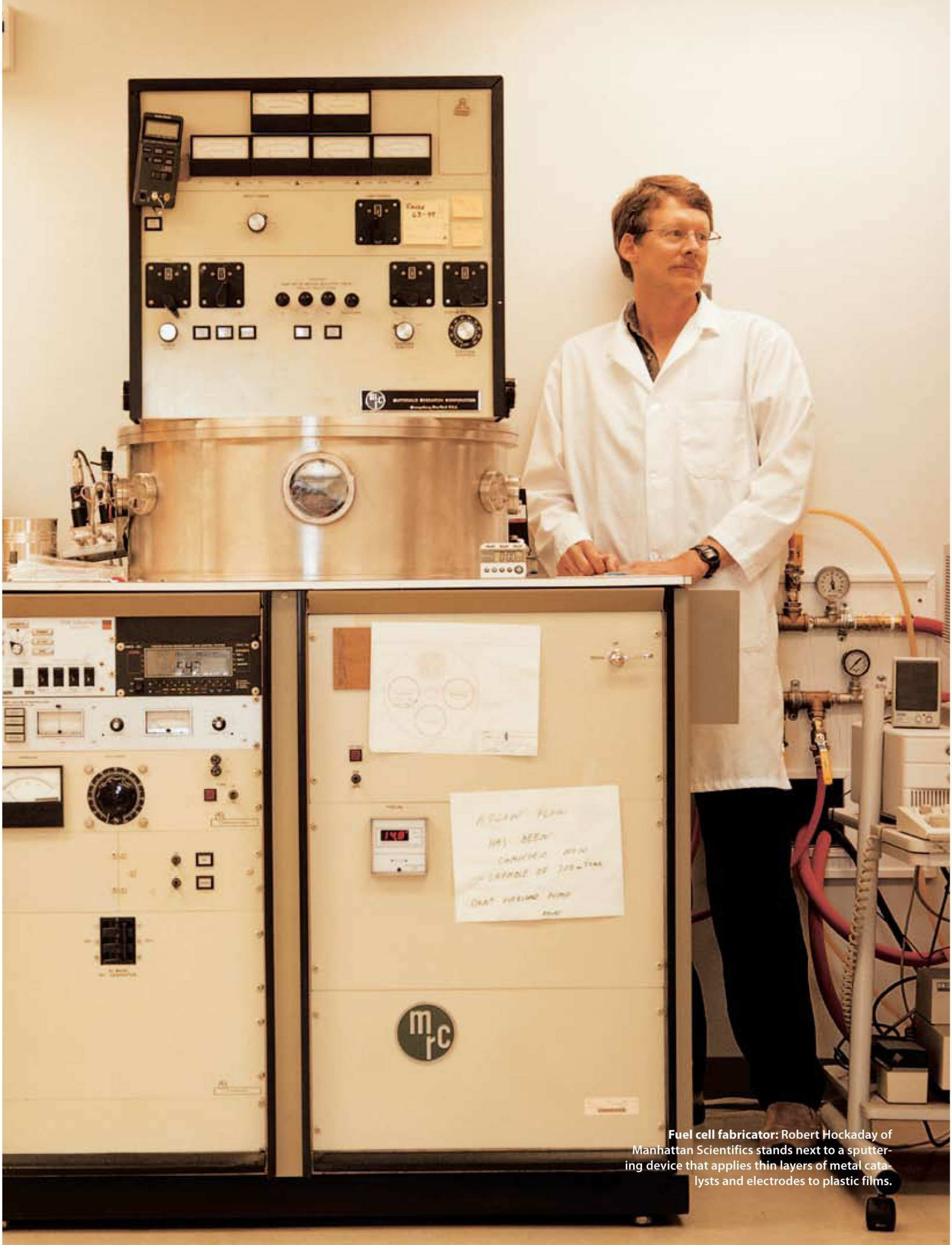
These miniature power plants, called micro fuel cells, promise a huge power boost for portable electronics ranging from cell phones to laptop computers to future generations of power-hungry, Web-enabled handheld devices. Today's best lithium-ion cell-phone batteries provide an average of only four hours of talk time; micro fuel cells could provide up to 20 hours of talk time. And after that, instead of plugging in the cell phone overnight, or swapping batteries, you'd just snap in a new methanol cartridge.

Fuel cells are, of course, already bursting onto the market in other forms—and in far bigger sizes. Buses powered by fuel cells are making their first appearances, and cars are next *(see "Fill 'er Up with Hydrogen," TR November/December 2000)*. Fuel cells that provide backup power for homes and offices are becoming available, too *(see "Power to the People," TR May 2001)*. Electrolux has even prototyped a cordless fuel-cell vacuum cleaner. Among other advantages, fuel cells use readily available sources of energy—namely, hydrogen or methanol—and produce only water, carbon dioxide and heat as waste products.

Now, industry is gearing up to make fuel cells small enough for consumer electronics. Building practical fuel cells this small—devices that produce one-tenth of a watt to 50 watts—presents huge engineering and materials challenges, but the market opportunity is enormous. "Portable fuel cells have the real potential of being profitable in a shorter time span than either stationary or automotive fuel-cell applications," says Atakan Ozbek, vice president for energy research at Allied Business Intelligence, a technology research firm in Oyster Bay, NY. "In five years this could be potentially a billion-dollar-a-year market. This industry is going to kick."

Not surprisingly, a race to commercialize the technology is in full swing and includes everyone from Motorola and Korean electronics giant Samsung to startup companies like Hockaday's. The competitors are betting on different designs—and even slightly different chemistries—but they share a common goal: taking a bite out of the $6 billion world market for rechargeable batteries.

The first successful application is likely to be methanol fuel cells that produce approximately one-tenth of a watt



Fuel cell fabricator: Robert Hockaday of Manhattan Scientifics stands next to a sputtering device that applies thin layers of metal catalysts and electrodes to plastic films.

and can recharge conventional batteries, liberating consumers from the dashboard lighter or the wall socket. Next will be fuel cells small enough to actually fit in the battery compartments of existing phones and yet powerful enough—one watt for cell phones, 50 watts for laptop computers—to be used for direct power.

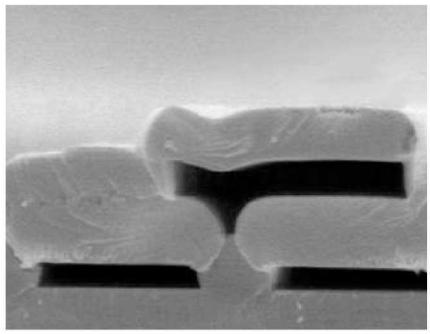
Even farther on the horizon, microchips will be directly powered by built-in fuel cells. These fuel cells will provide a boon to miniaturization by removing the need for separate power sources. They'll be custom designed to provide precise power needs. And production costs should drop when both chip and power source are fabricated as one unit. Self-powered chips, in turn, could enable a future generation of self-sufficient gadgets, like tiny networked sensors that can operate in remote areas, detecting pollutants, biowarfare toxins or anything else that needs detecting, and sending out the data for months.

GETTING SMALL

The problem with conventional batteries is that they rely on electrochemistry that dates to the late 18th century, and they have some severe limitations. Most notably, once the supply of chemicals inside the battery has finished reacting, the battery goes dead. You must either connect it to a charger plugged into the wall socket or throw it away—preferably in the recycle bin because of toxic ingredients like cadmium and mercury. And batteries aren't likely to get much better; virtually every chemical combination has been tried, says Shimshon Gottesfeld, chief technology officer at Albany, NY-based Mechanical Technology, a company developing micro fuel cells. "Even the best batteries have little chance to go very much higher" in the power they can produce by weight, he says.

Fuel cells are more complex, but they carry fundamental advantages. As long as there's a supply of hydrogen or methanol, the fuel cell will produce electricity. Moreover, thanks to the high-energy fuels they use, fuel cells produce more energy for their weight than batteries ever will.

But fuel cells are tough to engineer, and the smaller ones are toughest of all. The design challenges for micro fuel cells start with the choice of fuel. Hydrogen is impractical; it's a gas and must be compressed at very high pressures, and even then it requires tanks too large for portable electronics. Methanol/water mixtures are more easily stored in a small fuel cell, but using them creates new engineering hurdles. To manage a liquid fuel, tiny pumps and pipes are required. Then there's the waste water. Not even the most ardent cell-phone users would tolerate power supplies that drip on their shoulders, so fuel cells must evaporate the water. All fuel cells create heat; the small versions operate at anywhere from 15 °C to a scalding 60 °C. While this provides a means to evaporate waste water, it also requires the right balance of insulation and venting.



GEORGIA INSTITUTE OF TECHNOLOGY

Microfuel: Methanol flows through 10-micrometer-wide channels (black) in silicon covered by a catalyst and proton membrane.

Cramming all of this into a nifty package the size of a couple of AA cells presents a real challenge. And given the fierce competition to commercialize a micro fuel cell, most corporate players are cagey about how they've begun solving these problems. "There is a lot of posturing among the companies, but that is what you'd expect in the early stages as they try to maintain their positions," says fuel cell watcher Chris Dyer, editor of the *Journal of Power Sources*. But, he adds, "This isn't smoke and mirrors. It's a real technology and just requires some clever engineering to make it work."

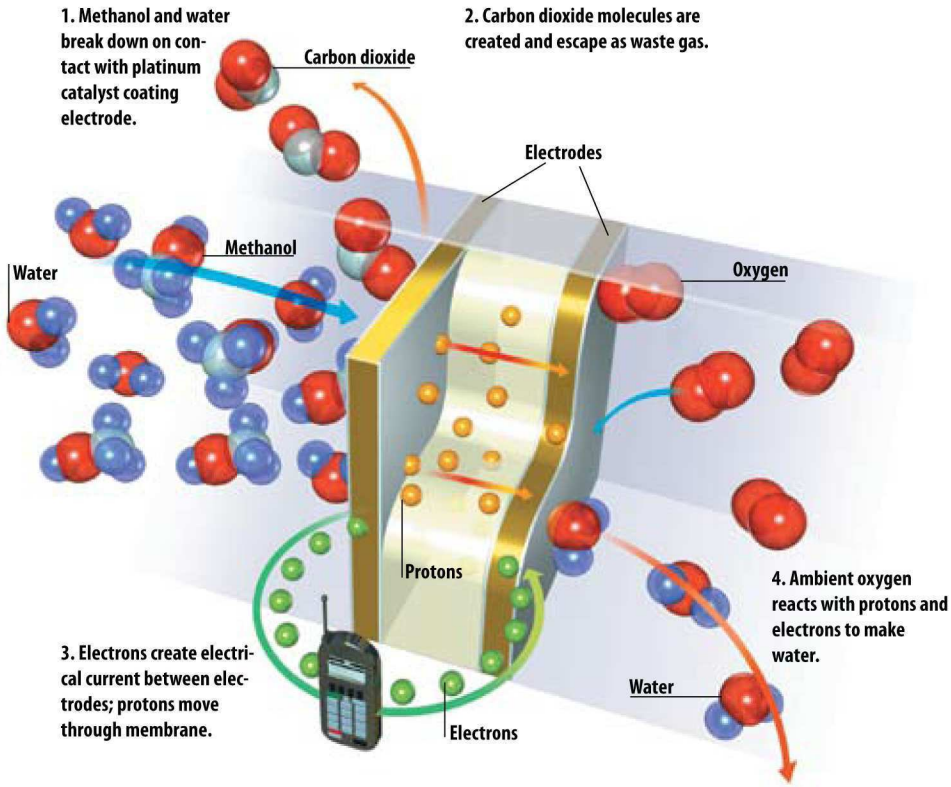
Most observers predict that the first micro fuel cell on store shelves will be a charging device using methanol. A half-dozen companies are working on variations on this theme, including Manhattan Scientifics. In Hockaday's design, the fuel cell components aren't arranged in a stack, like traditional automotive fuel cells. Rather, they're laid out side by side, like components on a microprocessor, making them amenable to semiconductor-manufacturing techniques.

Mechanical Technology has already cofounded a company that sells refrigera-

SLIM FILMS

Methanol Micro Fuel Cell

Methanol micro fuel cell designs vary, but all make electricity through reactions involving diluted methanol, catalysts and oxygen.

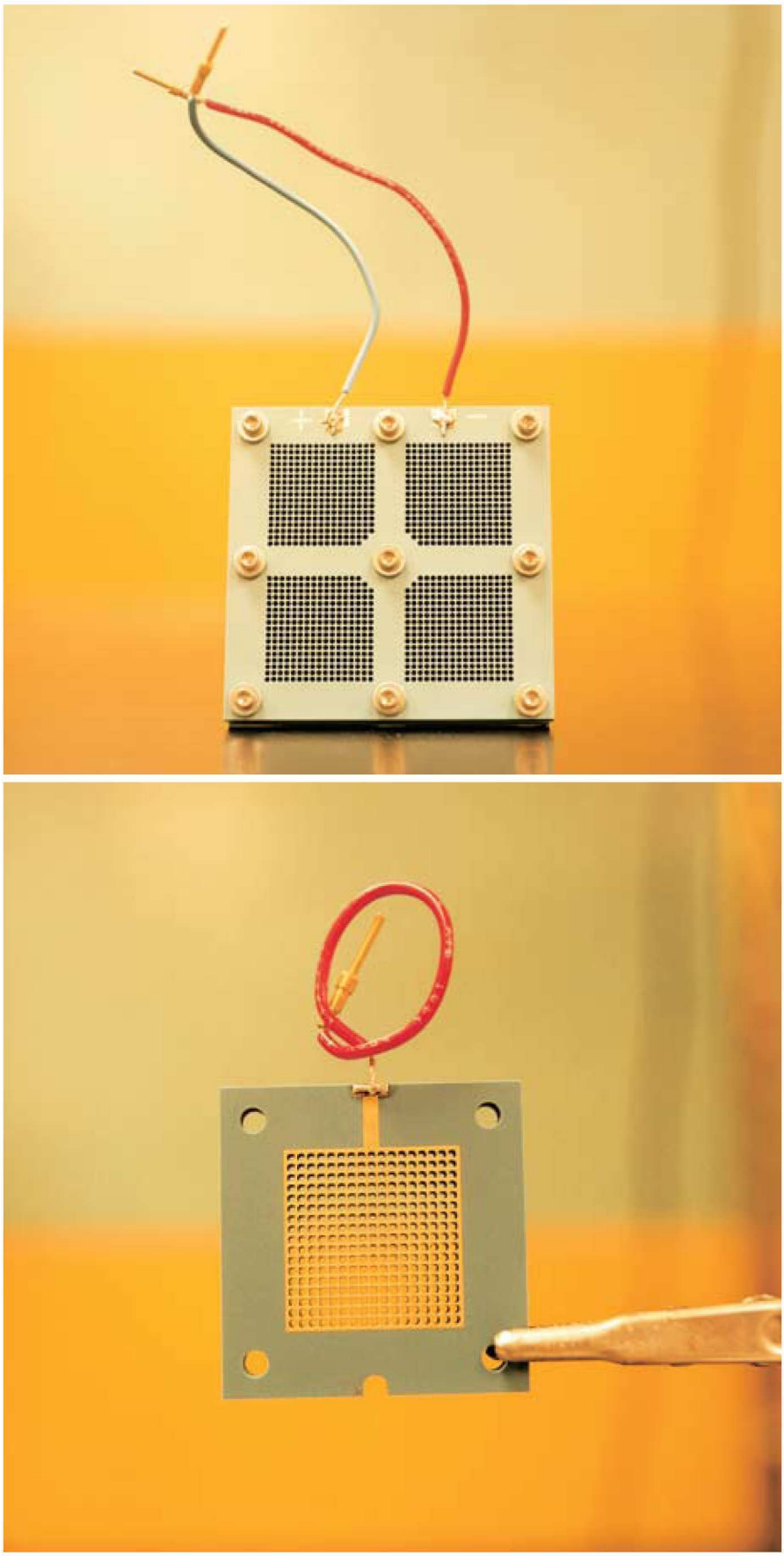


The Hale and Dorr community was profoundly saddened

by the tragic events of September 11, 2001.

To those who have lost loved ones, friends and colleagues,

we offer our deepest sympathy and condolences.



Charge it: Motorola's prototype micro fuel cell (top) has four cells, is five centimeters wide and produces 350 milliwatts, enough to recharge a cell-phone battery. A ceramic covering allows air to reach the catalyst and vents heat and water vapor. Methanol enters on the other side. Nine bolts hold the assembly together. A single cell cover (bottom) is displayed with an alligator clip.

tor-sized commercial and residential fuel-cell power plants. Now, Mechanical Technology is setting its sights on smaller things, starting with charging devices. "We are very optimistic about the prospects for commercializing this," says Mechanical Technology's Gottesfeld, former director of the Los Alamos lab's fuel cell research program. "We are not only looking at chargers but a complete system for cell phones. We're also looking at other possibilities like laptops, the toy market and power tools."

Motorola and Korea's Samsung are also actively developing prototypes. Hyuk Chang, a principal researcher at the Samsung Advanced Institute of Technology outside of Seoul, says the company's goal is to demonstrate working models in a year, again with charging devices leading the way. "I think it will take another two years to get from the lab into customers' hands," says Chang. "The hard question is what will be the first application."

At Motorola, fuel-cell project leader Jerry Hallmark is pursuing a strategy that promises smaller fuel cartridges. He says the company has developed tiny fluid systems that would continually recycle the water in the methanol-water fuel mixture. Replacement cartridges could just carry undiluted methanol. "The fuel cell can't run on concentrated methanol; it needs a dilute solution. But you don't want to carry a dilute fuel," he says. Hallmark adds it will likely take three to five years for any company—including Motorola—to begin selling a product.

PACKING A PUNCH

What Motorola and the other companies want most of all, though, are battery-like fuel cells that snap right onto phones and other electronics, to power them directly. "The cell phone is one of the hardest, because people would like to replace their battery with a fuel cell the same size. I'd love to be able to give it to them, but we're a long way from having something like that," Hallmark says.

To realize this vision, the companies are pursuing varied strategies. New York City-based Medis Technologies believes it can make a fuel cell that could replace the cell-phone battery, providing 20 hours of cell-phone talk time and hundreds of hours of standby on a single fuel cartridge. Robert K. Lifton, Medis's chief executive officer, says the company is using a proprietary liquid electrolyte that can operate with

higher concentrations of fuel—and provide correspondingly more power—than conventional alternatives. But Medis is not saying exactly how it works. "We have around 17 patents filed, and we're waiting to get them before we discuss the details," says Lifton. The business strategy, though, couldn't be plainer: it's the razor blade approach. "The payoff for us would be the refills," at about $1 per refill, explains Lifton. He says Medis will have a prototype by the end of this year.

Another strategy involves carrying methanol as the fuel and then converting it when needed into hydrogen. Because hydrogen packs more power by weight than methanol, the scheme could produce more powerful and efficient fuel cells. Robert Savinell, a chemical engineering professor at Case Western Reserve University, is trying to build just such a small fuel cell; so far his group has built a 25-square-centimeter prototype.

The chemical conversion of methanol to hydrogen—often called "reforming" by engineers—is simple enough technologically, except when you try to do it on a thumbnail-sized device. "People have built reformers on a large scale for kilowatt applications, so the question is not whether it works. The question is whether you can make it small enough to fit in a cell phone or laptop," says Motorola's Hallmark.

CHIP POWER

Beyond the day when electronics come with built-in fuel cells instead of batteries, another technology frontier looms: building fuel cells directly on chips. Already, Savinell's group at Case Western has built a prototype only 1.5 centimeters by two centimeters. His group used microfabrication techniques to "print" five to six layers of fuel cell components—the membrane, electrode and catalyst—on ceramic and silicon wafers, and more recently on a flexible polymer material. At this scale, he's using hydrogen as a fuel, stored as sodium borohydride and released with a platinum catalyst. "The hope is to provide power on a chip with a sensor and a transmitter—a totally self-sufficient device," Savinell says.

Researchers at the Georgia Institute of Technology, MIT, Stanford University and Sandia National Laboratories in Livermore, CA, are also working on building chip-scale fuel cells. To make these devices run on easily stored methanol, Paul A. Kohl, a professor of chemical engineering at Georgia Tech, is fabricating tiny channels on silicon through which methanol and water can pass. These channels could be created on a conventional silicon-chip assembly line. "You could design the fuel cell to supply exactly the power you want and be the size you want," says Kohl.

Beyond shrinking fuel cells to the chip scale, another long-term goal is enabling fuel cells to directly tap the power of hydrogen but avoid high-pressure tanks. One ambitious approach would make use of carbon nanotubes: pipelike carbon molecules that have the ability to store and release hydrogen. Researchers envision nano canisters full of hydrogen that could keep fuel cells humming, but this will require breakthroughs in materials and manufacturing methods, says Michael Heben, leader of a nanostructured-materials group at the U.S. Department of Energy's National Renewable Energy Laboratory in Golden, CO. "It could be that someone puts their finger on this in the next week, or it could take 20 years," he says.

The most credible, reproducible results to date, says David Tomanek, professor of physics at Michigan State University, were achieved by Mildred Dresselhaus, a physicist at MIT, and colleagues at the Chinese Academy of Sciences who reported finding a way for carbon nanotubes to store 4.2 percent of their weight in hydrogen. That may be enough for micro fuel cells, Tomanek says. "It will be lighter, smaller and safer than a tank, even at four percent, and this could be done in a couple of years. But I am an optimist," he says. Dresselhaus herself is more guarded: "At the moment, we don't have the magic wand. We have an opening that says, 'This is something to look for.' The next step is still missing." That next step could come within this decade, she adds, but "we need to have a major breakthrough."

Other electronics giants are also experimenting with carbon molecules to improve micro fuel cells. NEC has reported using horn-shaped molecules known as carbon nanohorns as a substrate for platinum catalysts, providing more surface area for stronger chemical reactions and more power. And Sony says it is using soccer-ball-shaped carbon molecules known as fullerenes—the base components of carbon nanotubes—to construct better electrolytes.

Meanwhile, the first micro fuel cells are rapidly nearing the market. Of course, the prototypes need continual fine-tuning to make sure fuel can't leak and to increase their efficiency. But these hurdles are relatively minor, industry watchers say. After all, batteries had their share of development troubles, too. The first high-energy lithium batteries tended to catch fire and even explode. As any cell-phone owner knows, those problems were solved.

There are plenty of reasons—about $6 billion worth, in fact—to suggest the same will happen with micro fuel cells, putting these remarkable tiny power packs in millions of consumers' pockets. Indeed, as micro fuel cells emerge from cluttered labs like the Los Alamos outpost of Manhattan Scientifics, they may put batteries, with their limited power and heavy-metal waste disposal headaches, into technology's recycle bin.

The Micro Fuel Cell Market Race

COMPANY	PREDICTED FIRST PRODUCTS	COMMERCIALIZATION TARGET
PolyFuel (Menlo Park, CA)	Fuel cells as original equipment on next-generation electronics	2003
Manhattan Scientifics (New York, NY)	Chargers for cell phones	2003
Mechanical Technology (Albany, NY)	Not disclosed	Not disclosed
Medis Technologies (New York, NY)	Chargers/cell-phone battery replacements	2003
Motorola (Schaumburg, IL)	Chargers/next-generation cell phones with fuel cells	2004-2006
Samsung (Seoul, South Korea)	Next-generation cell phones with fuel cell	2003

NEW LIFE for DUPONT

BERND AUERS

INTERVIEW WITH CHAD HOLLIDAY

Venerable DuPont is one of the United States' oldest and most successful corporations. Founded in 1802 as a gunpowder and explosives maker, it became a household name by giving the world nylon, Lycra, Teflon, Kevlar and other materials, many of them based on revolutionary breakthroughs in polymer chemistry.

Indeed, for much of the 20th century, DuPont—and its fabled central R&D lab—has been viewed as ground zero of innovation in the chemical and materials industries: it currently spends nearly $2 billion a year on research and development. But some of these innovations have come at a cost. DuPont pioneered chlorofluorocarbons, which were phased out in the mid-1990s due to their role in the destruction of the atmosphere's ozone layer. And the company's various manufacturing processes, though perfectly legal, have made it one of the world's largest industrial polluters.

At the same time, you don't live to be a two-century-old firm without reinventing yourself several times, and the chemical giant is currently attempting another reinvention—recently shedding its energy and pharmaceuticals businesses to concentrate on new ventures in biotechnology, organic displays and even superconductivity.

In advance of the firm's bicentennial anniversary, *Technology Review* editor at large Robert Buderi visited DuPont's energetic chairman Charles O. "Chad" Holliday Jr. in his headquarters in Wilmington, DE. The two spoke in depth of DuPont's technological future—especially the effort to combine traditional chemistry with biology to create new bio-based materials. They also examined DuPont's environmental performance, the Kyoto protocol and the need to balance economic success with environmental responsibility and social progress—challenges reflected in Holliday's position as cochair of the World Business Council for Sustainable Development. In short, they discussed where DuPont is headed in the next 200 years—well, at least in the next decade.

TR: DuPont is at once an old company, 200 years old, and a new company. You're making some of the same products you did decades ago, and pioneering new things.

HOLLIDAY: The key in innovation is to keep taking old products, finding new uses for them, different adaptations, while you bring in new things. We are adding biotechnology, a major new platform, while we're taking things like nylon, which has been around for 60-plus years, into new forms and uses. We just introduced a new form of nylon that has a very soft feel, and fantastic wear resistance. So as an example, if we can take nylon to a new level of performance and give you a reason to replace the carpet in your bedroom…that's what it's all about.

TR: The challenge of innovating in your existing businesses and growing new businesses isn't really new, though. Are there other aspects of this that are?

HOLLIDAY: Historically, we liked to get everything done with a bow tied on it, and then go to customers and say, take it. You can't do that anymore. You've got to get the end user working with you every step along the way. Take our new soy milk that we're putting out with General Mills. We have a sweeter-tasting soybean, and some very good technology to process it. So we went to General Mills and said, we can sell it to you and everybody else as an ingredient, or we together will perfect the packaging, the distribution, the flavors, the process and make it a 50-50 joint venture. So we did it. It's called 8th Continent soy milk, and in many parts of the United States you'll find it on your supermarket shelf today.

We also have an MIT alliance that is really about understanding technology from the outside—and being sure we're focused on customer needs. What MIT did was pick a major business/market arena to focus on and identify a leading industrial partner to work with. For example, they have a deal with Ford in automotive and Merck in human health. For bio-based materials, they chose DuPont. So we have now about 30 specific research programs ongoing through our relationship with MIT on bio-based materials. It's a five-year process. We're about a year and a half into it now. It's a big commitment—$35 million on our part—but we like the way they bring in a lot of outside thinking, a lot of new ideas. And the business school—the Sloan School—is a part of this, so we look at the business model at the same time.

TR: Let's talk more about bio-based materials. You once told me if you could pull off this "biotech thing" it would really be something special. Is this what you were talking about, the merger of biotech and chemicals?

HOLLIDAY: Yes. There's tremendous focus now on genetically modified plants. We get $1 billion worth of revenue from genetically modified plants today. That's going to be a very important business for us going forward. On the other hand, there's human health—using the knowledge of genomics to make better medicines. That's very important. But we've gotten out of pharmaceuticals. In between there's this big space called bio-based materials. The key here is what's being called bioengineering—putting basic chemical processing capability and fundamental engineering skills together with genetics to create new technology platforms, so we're no longer just depending on the petrochemical route. I don't know anybody in the world better equipped to do that than we are, because we started our first research in bio-based materials in about 1985. So if you've got a problem, it gives us the option to take either the traditional chemical route or the bio route, or some combination.

TR: Has it changed the kind of people you hire?

HOLLIDAY: Oh, sure. I can't hire many people with bioengineering degrees yet, so we've been purposely placing our best process design people with our bio folks—putting them in the same building and saying, you guys talk to each other. I like to say we're writing the handbook on bioengineering today.

TR: You have a new corn-based polymer ready for the market, don't you? Is it DuPont's first bio-based material?
HOLLIDAY: It's called Sorona. It's a bit different than polyester, but it's in the polyester family. It has very good dyeability. It's got stretch recovery. It's not quite as good as Lycra, but if you're wearing a jacket of it, it's got a little more give, so it's more comfortable all day. We're also looking at it in carpets. Half the molecules are going to be made from corn through biotechnology. It's our first new polymer platform in 30 years.

TR: What else excites you most about what's coming down the pike?
HOLLIDAY: I can't remember a time where there are more things that really have the potential of being really big—because they're aimed at important problems. Nylon was kind of like that. It was the right product at the right time. It was wartime—you needed parachutes and you needed reinforcement for tires. I think what we have now is a different kind of war. It's a war where environmental performance, market knowledge, intimate customer knowledge, pace and innovation are the "fronts" that will determine the sustainability of global business.

We have major superconductivity programs: nobody's made a lot of money on superconductivity yet, but there's a potential, and we're making progress. We've got a new superconducting filter system for cell-phone base stations that is in trials now. We've got some key materials for fuel cell systems that might power a building, or in the long term, your automobile.

TR: Are displays, like those made of organic light-emitting diodes, another big potential growth area for DuPont?
HOLLIDAY: Major. It's clear, people need better displays. They need less energy consumption. In addition, they need them made out of plastics so they won't break. We work with Uniax, a little company we bought out on the West Coast from Alan Heeger, who won a Nobel Prize for chemistry last year. DuPont holds a majority stake in Polar Vision, an innovative optical components and lamination services provider serving the display industry. And we've ventured with RiTEK Display Technology in Taiwan to produce OLED [organic light-emitting diode] glass panels exclusively for DuPont Displays using proprietary technology from DuPont and Uniax. So we're putting together a consortium of folks that we think can turn out a display that's polymer based—far brighter, lighter, flexible, break resistant and much more energy efficient than the current technology. We showed prototypes at the last major technical show. We'll have products in the marketplace next year.

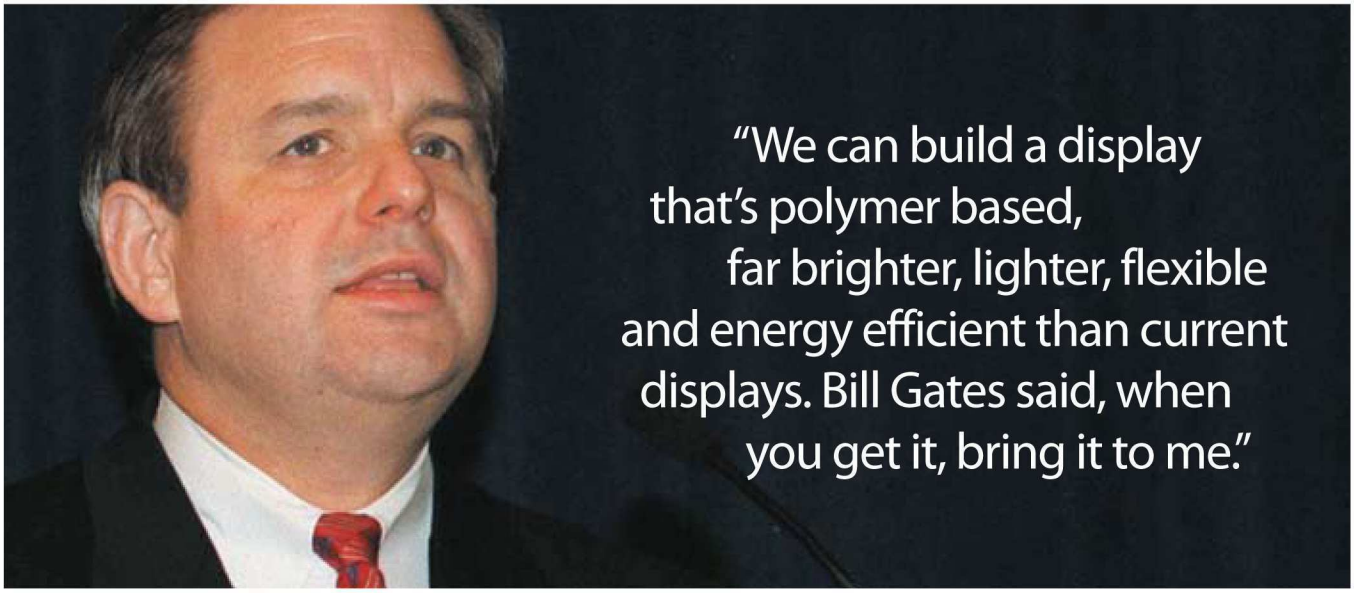
I'll never forget a meeting with Bill Gates three years ago, talking about what we could do together. Basically, what he said was, "I need a display people can read. Because even at Microsoft, if it's two pages, we print." And so if we could get a display that's so good you would prefer it over paper and like it enough to even want to sit back and read it in bed, you can. That's going to happen, and we can play a role in that gigantic market.

TR: So did you guys work out a deal?
HOLLIDAY: Well, he said, as soon as you get that display, bring it to me.

TR: It's interesting, you're talking about DuPont and Microsoft entering into the same turf, and that's not what you think of with a chemical company and a software company.
HOLLIDAY: It's a very good observation, because one of my bigger competitors in the displays market is Sony. They come at it from the user end, we come at it from the solution end. And so we're both kind of crowding each other's space. In the old days, I would just go sell Sony, or Sony's supplier, a material. Now what I want is to sell a display or a component for a display. I think you'll see us do more and more of that.

TR: So do you think that in 10 or 20 years, DuPont will be a much different company?
HOLLIDAY: Without a doubt, because *every* 10 or 20 years we are a much different company. We made a very strategic decision a couple of years ago to get out of the energy business. We made another key decision earlier this year to get out of the pharmaceutical business. Great business, great industry, but when you're a billion-and-a-half-dollar pharmaceuticals player with a $500 million pharmaceuticals research budget and the other

guy's got $3 to $4 billion, how do you really make a difference? In this case, we weren't willing to commit up to 25 percent of our total company research budget to a business that was no longer a strategic priority. We'll focus where we'll make a difference for our shareholders. So in plant science we will be a leader, in bio-based materials we will be a leader, and we will lead in electronic systems. We're the third-largest company supplying materials to the electronic industry today. I'd like to be number one. These are areas where we can win, and so that's our thrust.



GETTY IMAGES

TR: You talk a lot about the environment and sustainability. It doesn't seem to fit the image of a big chemical company that's one of the world's largest polluters.

HOLLIDAY: About 12 years ago, we were labeled the largest industrial "polluter" in the U.S. based on EPA's Toxics Release Inventory reporting. We were there because of our deep-well disposal of aqueous wastes. These were legal wastes, but we just put more stuff out there than anybody else. We decided that's not where we wanted to be. And we concluded that if we put our engineering talent to it, we could clean up our processes and make money for our shareholders at the same time. It goes without saying that we went after the bad actors first—anything that posed a serious risk to human health and the environment.

TR: How does the energy picture figure into this for you?

HOLLIDAY: There are two ways. First, we set a goal that by 2010 we would cut global greenhouse gas emissions by 65 percent, using 1990 as the base year. We had some pretty good ideas how to do it, and we expect to be at 60 percent reduction this year, so we're almost there. Second, we said we would get 10 percent of our energy from renewable resources by 2010. This was pretty gutsy. We could do it tomorrow if we just wanted to pay the price, but that's not the idea. We want to do it in a way that makes money. We just had a review of this goal, and we've made a lot of progress.

TR: Not going to hit the target?

HOLLIDAY: We will. We're at two percent for 2000, and we have several years left to go. We're examining all our options. Right now one that appears to offer us the most is gas from landfills as a substitute for natural gas. We've got about seven sites where we've already found a landfill close enough to our plant that we can just run a pipe and use it. I can visualize where landfill gas could be a big part of the 10 percent and make us money doing it.

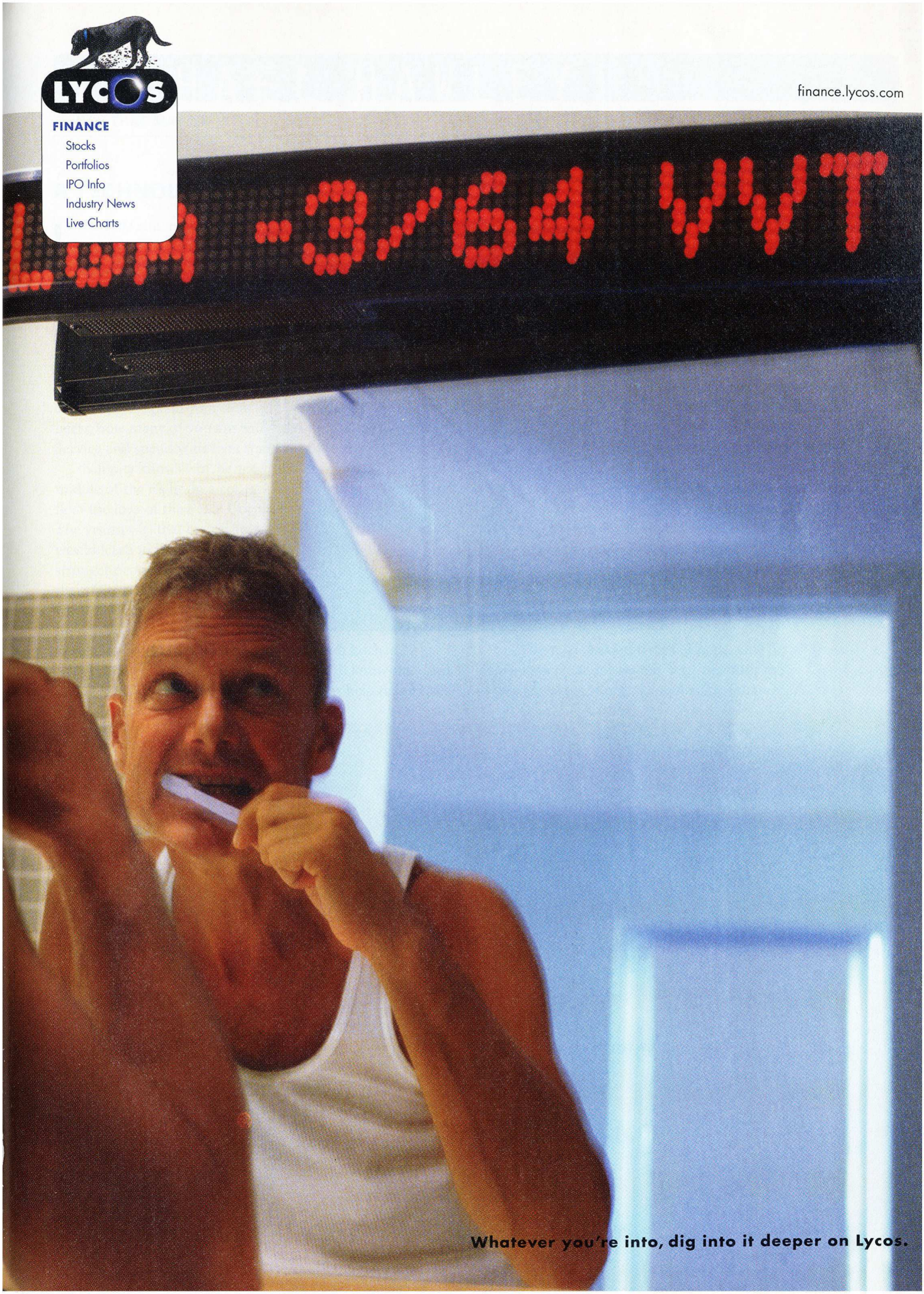
TR: Where do you stand on the Kyoto protocol?

HOLLIDAY: We believe that global warming is an issue, and we believe the world should start taking pertinent steps around that. Some aspects of the Kyoto protocol are a very good start, such as the emissions trading mechanisms. We think by getting a trading system set up where the lowest-cost company can do it and sell the credit to somebody else is a very positive step forward. Aspects to the Kyoto protocol are just not right, such as developing countries not having to get into the game early. It's hard to get all these nations together to do something, so why don't you start with the fundamentals of Kyoto and improve it, make it better?

TR: DuPont is one of the most global companies in the world and may be in a better position to see something about the economy than others. So I wanted to ask you for a bit of economic forecasting.

HOLLIDAY: Well, in September 2000, we were the first to come out and say, this economy is getting bad. And the initial responses were, what's wrong with DuPont? But about five weeks later, you saw a lot of reports just like ours. If you're selling materials, or making cars or electronics or clothes, the U.S. volume is off drastically. Europe has gone down—not nearly as drastically as the U.S., but it has turned down. Asia's turning down, and South America's down. I can't recall a time when the volume was simultaneously dropping in all the major regions of the world.

Now, there are some signs that could say the U.S. is bottoming out right now, but we're not banking on that. The dollar for us is at a 15-year high. And then I've got high energy prices. So when you put all those things together, it's not a very pretty scenario. We don't see the upturn yet in sight. I hope, in a few months, we will. But we're not going to gear up our plants and start moving until we can see firm demand. TR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The men and women of EDS are deeply saddened by the recent tragic events in America. We extend our profound sympathy to everyone who suffered.

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A TECHNOLOGY CORPS

It was 2:00 a.m. on October 14, 1960. Ten thousand students were waiting in front of the student union building at the University of Michigan. As the weary candidate climbed the steps, the audience began chanting his name.

Senator John F. Kennedy had just flown in from New York, straight from a television debate with Vice President Richard Nixon. He spoke to the students off the cuff, delivering a speech that in just a few sentences would launch the Peace Corps. "How many of you who are going to be doctors are willing to spend your days in Ghana? Technicians or engineers, how many of you are willing to work in the Foreign Service and spend your lives traveling around the world?"

Nobody knows why Kennedy picked that moment, in the middle of the night on a college campus in the Midwest, to float the idea of the Peace Corps. But the effect was electric. The vision was that by learning to serve, a new generation would learn to lead. They would return from the field as stronger people, better not just from learning how to apply their talents, but from having learned much more about themselves and their place in the world. "There is not enough money in all America to relieve the misery of the underdeveloped world in a giant and endless soup kitchen," Kennedy later declared. "But there is enough know-how and knowledgeable people to help those nations help themselves."

In August of 1961, the first Peace Corps volunteers stepped onto the tarmac in Accra, Ghana. By the end of 1963, 7,300 volunteers were working in more than 40 countries; by 1966, the ranks had swelled to more than 15,000 in about 60 countries. And that, alas, was the peak. Under the pall of the war in Vietnam, the movement shrank.

The good news is that President Clinton "expanded" the Peace Corps—to 10,000. The bad news is that pitifully few Peace Corps workers have the kind of training that enables them to transfer the best ideas from Western labs into developing countries. Most volunteers have backgrounds in business, education, health care or ecology. A thin slice of the pie, about four percent, falls into the category of "other." And in that sliver you find technologists. It's a hugely disappointing minority.

Why so few computer scientists and engineers join the Peace Corps is unclear. Perhaps it's because most technologists are trained in environments that require a lot of infrastructure and support in order to push through to the next discovery. It's hard to break new technological ground in a subsistence village. Another factor could be that there's a very well oiled path from the university into the high-tech job sector. Most people who start down that path stay on it.

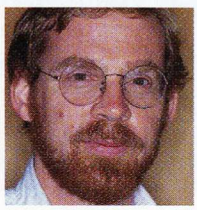
There are, however, rays of hope. One fledgling approach that directly addresses the "four percent problem" is Geekcorps (www.geekcorps.org). Launched by Ethan Zuckerman, who

In August 1961, the first 51 Peace Corps volunteers met with President John F. Kennedy at the White House to inaugurate the new organization.

CORBIS

cofounded the successful Web service company Tripod, Geekcorps sends SWAT teams of technologists into the field to give the world's poorest people access to the Internet. The Geekcorps folk work with local communities to build the infrastructure needed to bootstrap local businesses. In an interesting echo of the Peace Corps, this outfit too began in Ghana. In fact, that's where the idea first came to Zuckerman: he went there on a Fulbright scholarship in 1993.

Geekcorps volunteers spend four months on the ground in developing nations, working to help partner businesses on a technical level. This corps of people and backers is largely drawn from the pool of successful U.S. technocrats. One volunteer, for example, came from the management and technology consulting firm Accenture, where she became an advocate for more corporate involvement in developing-world efforts. The firm now has several initiatives looking at how developing nations can embrace information technology to achieve economic growth. Getting a taste of the reality in Ghana, through one of its employees, translated into boundless energy and fresh leadership for Accenture—and that energy is what keeps these companies thriving.



Pitifully few Peace Corps volunteers have the kind of scientific or technological training that enables them to transfer the best ideas from Western labs into developing countries.

Often, through these experiences, new opportunities arise for both volunteers and their partners in developing nations. Armenia Nercessian de Oliveira was a United Nations official for 16 years. Working in hardship countries, she saw many beautiful local handcrafts and was struck by what happened to them en route to the world market. In Africa, she saw handcrafted masks being sold for $15; back in the States, Bloomingdale's would sell the same mask for $300. Enter Novica United, founded by Nercessian with her daughter and son-in-law. Novica applies an Amazon-like approach to the marketing and distribution of local handcrafts from around the world. By connecting local offices in dozens of countries to the Internet, Novica has organized a vast online catalogue of goods created by thousands of regional artists. These items can then be sold directly to consumers at far below Bloomingdale's prices, returning a much greater profit to the artists.

For the recipient, each little gift, each product Novica ships, is a key that opens a doorway to another part of the world—a tangible, evocative connection to a living artisan, a person with a name, face and life story. Novica profits because its networked approach eliminates legions of middlemen. At the same time, the company is promoting a new kind of savvy eco-consumerism. This is a "good karma" company par excellence.

Novica's business, if it succeeds, could help conserve indigenous crafts and cultures. Like Geekcorps, it is pursuing a path that heightens public awareness, enriches communities, elevates tastes and deepens sensibilities. As technology evolves, it is important, and I would argue critical, to be able to hold in one hand an ingenious handmade toy from Ghana and in the other some sort of beeping, blinking, battery-powered, computer-infused techno-toy. Pondering the difference between the two will help us come to grips with what sorts of artifacts we want to surround ourselves with and why.

In my last column, I argued how vital it is for scientists and technologists to get into the field and immerse themselves in reality, up to their eyeballs in different ecologies, different cultures, different ways of thinking and doing. Now more than ever, the world is our laboratory. We are connected to each

other through a fresh matrix of instant communication and easy travel. Burgeoning masses of people are constantly transforming the world. Humans have changed the climate, reshaped the land, harnessed rivers and extinguished species. Science gives us tools to change the world in incredible ways and at a frightening pace. But it can also help us restore some of what has been lost; it is also our compass for navigating the future. The question is: Who knows how to wield that compass?

The answer cannot come solely from scientists who have lived their lives in a lab. It must come from a new generation of technologists who have an active, first-hand sense of the world: scientists who know what the spirit of service means because they have served; engineers who have not just a textbook understanding of a problem, but who have had liberating experiences in settings that range from inner cities to outer wildernesses; inventors who know not only how to invent things, but how the processes of invention can help nourish a healthy, sustainable community.

The idea of dispatching volunteers with technological expertise to different parts of the world is gaining momentum. The MIT Media Laboratory, in collaboration with Harvard University's Center for International Development, recently launched a consortium called "Digital Nations." The consortium aims at bringing a broad set of next-generation technology projects, from e-commerce to health technology, to people in developing regions. The U.S. Department of State formed the Global Technology Corps, which enlists volunteers to share their skills in a number of areas, such as Web development or information science, with people around the globe. The leaders of the G8 (major industrialized countries) formed the Digital Opportunity Task Force to work on bridging the digital divide. Venture groups from Softbank to the World Bank are actively spurring new economic activity in developing regions.

This is encouraging news, but there's a long way to go. Right now, only seven graduates of MIT and four from Caltech are enrolled in the Peace Corps. And that just won't do.

COURTESY OF VISIONICS

FACE RECOGNITION

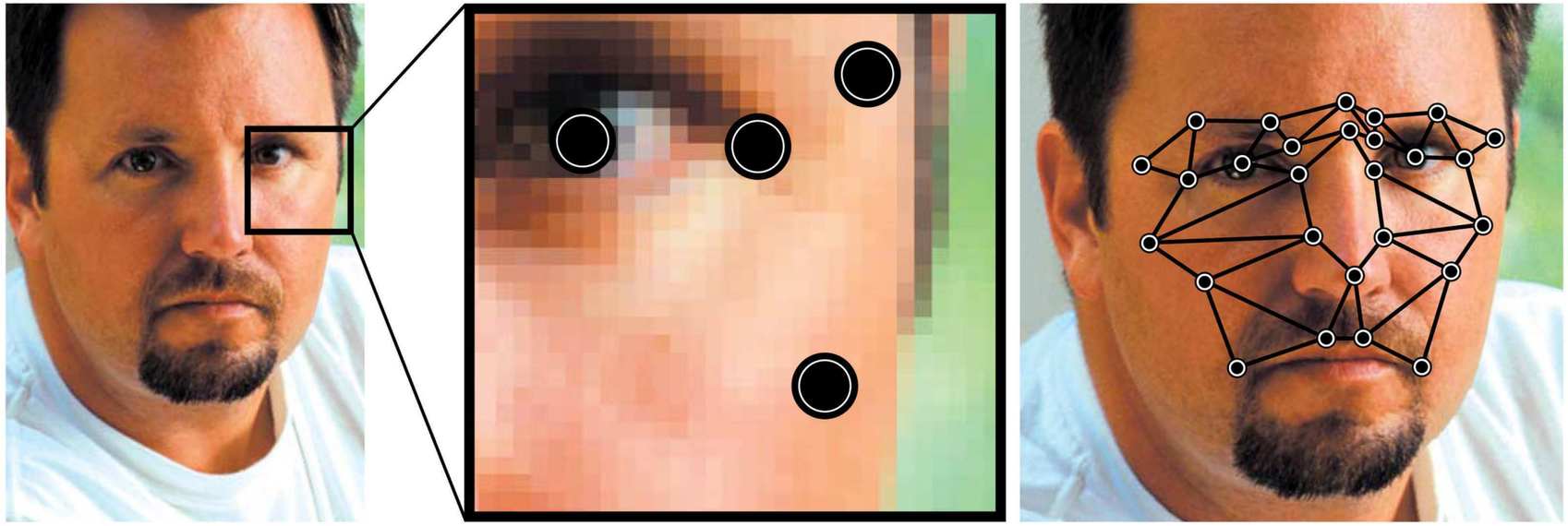
A camera and algorithm know it's you. BY TRACY STAEDTER

With airports tightening up security, biometric technologies such as face recognition may come on line. A few techniques exist to match known facial profiles against those of strangers in a crowd or to verify a person's claimed identity, as at an ATM. But two stand out: local feature analysis, developed by Joseph Atick, who founded Jersey City, NJ-based Visionics; and eigenface, first demonstrated at Helsinki University of Technology, later developed at MIT, and currently marketed by Viisage Technology of Littleton, MA.

A system based on local feature analysis uses a camera and computer to identify a person in a crowd. First it scans a field of view for shapes that could be faces. It then searches for facial features like those already stored in its memory. To be sure the eyes, nose and mouth belong to a living being—and not a mannequin—the program looks for eye-blinks or other telltale facial movements. The system then analyzes the pixels that make up the face image. It compares the darkness of each pixel to that of its neighbors, looking for areas where abrupt differences in value radiate outward from a single pixel. These changes can occur between the eyebrows and skin, the eyes and eyelids, or on features that protrude, such as the cheekbones and nose. The system plots the location of each pixel, known as an "anchor point," then connects the dots, forming a mesh of triangles. It measures the angles of each triangle and comes up with a number made of 672 ones and zeroes that identifies the face. The program attempts to match that number to a similar one in its database. There can never be a perfect match, so the program ranks how confident it is about the identification. And since the program plots the anchor points by bone structure, disguises such as beards, makeup and eyeglasses won't fool it.

Like feature analysis, the eigenface method also reduces a face to a number. But instead of looking at a collection of facial features locally, it examines the face as a whole. First it averages out a database of head shots to produce one composite face. Then it compares the face being identified to the composite. An algorithm measures how much the target face differs from the composite and generates a 128-digit personal identification number based on the deviation. Both systems offer security at the expense of constant surveillance. Whether society is willing to pay that cost is yet to be determined.

For an animated version of this illustration, go to www.technologyreview.com/visualize



OBJECT IDENTIFIED AS HUMAN FACE

ANCHOR POINTS LOCATED

CONNECTING THE DOTS FORMS A MESH OF TRIANGLES

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NEGATIVE IDENTIFICATION

43 PERCENT MATCH
NEGATIVE IDENTIFICATION

96 PERCENT MATCH
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RATINGS ARE DEAD; LONG LIVE RATINGS

Since January 2000, most new television sets have come with a V-Chip that enables parents to block programs with "objectionable" content—based on a system of letter ratings—yet less than 17 percent of all parents who own equipped televisions are currently using the chip. Why? Some argue that the V-Chip has been underpublicized or that parents don't understand the technology. Here's another partial explanation: while many parents *are* concerned that popular culture doesn't reflect their values, they also question whether any outside agency (like the TV industry organization that rates programs' content) can make media decisions for them.

Historically, media reformers have advanced two different kinds of rationales for any sort of ratings: one educational (providing parents reliable information for policing their children's media consumption), the other regulatory (controlling children's access to "unwholesome" material). But in the wake of the Columbine shootings, the weight has shifted to the regulatory side of the equation, with the Federal Trade Commission, the U.S. Senate Committee on Commerce, Science and Transportation and others investigating the "moral content" of popular culture, and proposals arising, for example, to make it a criminal offense to sell a violent video game to a minor. Calls for stricter enforcement don't empower parents; they reflect a suspicion that parents won't do what's best for their kids. Moreover, this system of enforcement relies on a definable "point of sale"—the ID check at an R-rated movie or an electronics store sales counter—while we are approaching an age when much content may be downloaded off the Web.

Maybe we are asking ratings to do too much. Ratings are value judgments, not objective scientific standards; but whose values do they reflect? Hollywood's 1930 Production Code, which regulated movie content for three decades, was authored in the context of a threatened boycott of American cinema by the Legion of Decency and other conservative Christian groups. Although its standards still influence our current ratings system, the code never reflected a national consensus—and in any case, a unified set of value judgments makes increasingly less sense within an ever more multicultural society. *The Lion King* may demean minorities, for example, but be rated as appropriate for all ages; Fundamentalist parents may object to the witchcraft in Harry Potter books. One parent objects to a single swear word; another figures kids hear that on the playground anyway. Other parents worry about animal abuse, homophobia and sexism, alcohol consumption, anti-intellectualism or blasphemy. No ratings system could accurately reflect all the different (and often contradictory) criteria. Ratings enforcement requires weighing some of these concerns over others.

What's more, the current ratings can only condemn "bad" content, not promote "quality" content. When we send our little darlings off to see a G-rated movie, what they are getting may be bland, boring and without any educational content; all we know is that it contains no nudity, profanity or violence. In an era of expanding media choices and diversified family values, will a one-size-fits-all system based on the least offensive content serve our needs?

What if we shifted emphasis onto education, empowering parents to play a more active role in assessing media content and sharing what they learn with each other? Compare the kinds of information you get from a letter-grade rating of a new gadget to what you learn when you read consumers' reviews of the device on Amazon.com. A variety of Web sites like www.kids-in-mind.com or www.filmvalues.com have emerged to fill this role for media—some attempting to simply describe the content so parents can judge for themselves if a video game or movie is appropriate for their kids, others providing different parents' assessments and discussing their underlying values. None reflects the full range of perspectives, or covers the diversity of current media. What we need is a neutral third-party organization—the cultural equivalent of the League of Women Voters—to create a commons where such discussions and debates about values can occur.

Current ratings can only condemn "bad" content, not promote "quality" content. We need to empower parents to play a more active role in assessing media and sharing what they learn.

In such an environment, parents could get insights about media choices from others who shared their values or be exposed to fundamentally different perspectives, as they chose. No longer a means of purely negative assessment, such a system would allow us to identify media products that actively embody our individual values. Most importantly, such a system would force parents to accept the responsibility for their own choices and talk with their children about their values rather than hiding behind an anonymous ratings system. Such assessments might also encourage the development of niche products targeting specific "values clusters" underrepresented in the current marketplace.

To be sure, these ratings couldn't cover every media product, but parents could exercise greater caution when they moved into unknown territory and report back what they found. That kind of system might be more labor intensive for parents, yet the current ratings scheme only promises easy answers to what are complex questions. With an alternative ratings mechanism, parents would be better informed about their media options but would not be able to impose their values on other people's families. Are you willing to make that trade? TR

RETHINKING THE PARADIGM PARADIGM

The philosophers got it wrong: scientists love new ideas—if they're right.

BY GARY TAUBES

A few years ago, I wrote a magazine article on the mathematics of the stock market. The assignment required that I spend considerable time interviewing the experts and studying the various theories, which is to say, whether stocks engage in a random walk of unpredictable fluctuations or whether their movements can be predetermined. If the latter is true, then the market is indeed a game that can be beaten by the better players, not just the lucky ones. I concluded, as do most experts and virtually all experimental studies on the subject, that for 99.99 percent or so of traders, buying a stock is a proposition, over the short term, at least, no more predictable than a coin toss, and losing money is as likely a result as making it. The remaining infinitesimal fraction comprises those pros who have spent fortunes on computing systems that will sift through vast amounts of data and find the exceedingly subtle patterns in the ebb and flow of stocks. They are also the ones who have the financial wherewithal to profit from those patterns before they vanish.

The "new economy" arrived, however, shortly after the publication of my article. I watched my friends and relatives, none of whom had shown particular signs of genius, cash in on the explosive growth of high-tech, Internet and dot-com stocks. New rules were in effect, I was told, and money could be made risk-free and hand-over-fist. After 18 months of passive-aggressive skepticism, I decided that perhaps I was wrong and they were right, and I bought a few tech stocks. The market then crashed, as the new economy revealed itself to be the old economy in the emperor's new clothes, and it took the bulk of my investment with it.

The moral of this story, as I see it, is that despite anything the philosopher of science Thomas Kuhn might have said to the contrary, new paradigms are extraordinarily enticing. In science, they are the breakthrough theories or remarkable discoveries, the revolutions—Kuhn's "conceptual world views"—that take a moribund field, mired in a swamp of conflicting data, and move it en masse to a new and fertile intellectual realm. In the business of technology, they are, in effect, the physical or financial manifestations of our prayers being answered: the next ubiquitous operating system, the latest revisionist approach to curing cancer or selling widgets online. They are, in their most trivial manifestations, "the new new thing," to quote the author Michael Lewis. They are also usually too good to be true—but we will get to that later.

GENE GREIF

As Kuhn saw it, and several generations of scientists, historians and journalists have told it since, new paradigms are accepted slowly, if not over the dead bodies of those who grew up with the old ones. Kuhn documented one great scientist after another, from Copernicus to Darwin to James Clerk Maxwell, who struggled relentlessly against the resistance of mediocre minds and later was vindicated. It was the German physicist Max Planck who set down the definitive words on

the subject: "a new scientific truth," Planck wrote, "does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it."

The salient question, however, is why the existence of "opponents"? And the answer, noted by Kuhn, although often ignored since, is surprisingly simple: a potential new paradigm or a remarkable breakthrough has opponents primarily because the data supporting it are not persuasive. Albert Einstein, for instance, may have refused to accept that God plays dice with the universe—the essence of quantum mechanics, which holds that the universe at its heart is a probabilistic and uncertain place—simply because the data supporting the existence of God's alleged gambling habit were then ambiguous. After a sufficient hypothesis and test, the data supporting the quantum mechanics revolution became compelling, and even Einstein was convinced (although perhaps not happy about it).

And that's the point: while scientists and technocrats will exhibit their fair share of inertial pettiness, the rejection of a potential new paradigm by the relevant experts is inevitably due to that institutionalized skepticism without which science no longer functions as a means to finding reliable knowledge. There are, after all, an infinite number of spectacular but erroneous breakthroughs for every one that stands the test of time. With these overwhelming odds, skepticism serves as the immune system for science, protecting the well-tested body of reliable knowledge from chronic infection by pathological phenomena that may play well in the media but can't be reproduced in the laboratory. This skepticism is even more important in confronting the latest alleged technological wizardry, because lives are often on the line, not just investments. As the physicist Richard Feynman put it, speaking in particular of the demise of the space shuttle *Challenger*, "reality must take precedence over public relations, for nature cannot be fooled."

Progenitors of new paradigms extract the truth from the swamp of conflicting data. If the evidence supporting them reaches a high enough pitch, skepticism will fade.

Such is not the case with mankind in general, however, scientists or otherwise. Good scientists are trained to be skeptical so as not to be deluded or, more particularly, as Feynman said, not to delude themselves. Indeed, in both science and technology, it is not embarrassing to be skeptical of a brilliant new paradigm or a remarkable breakthrough that turns out years later to be right. It's simply the nature of the job.

This leads us back to Kuhn, because virtually every paradigm-busting breakthrough, whether scientific or technological, is launched from a position of evidentiary weakness. The brilliant minds, the progenitors of new technological or scientific paradigms, are the ones who can extract the truth while it is still mired in that swamp of conflicting data. So it is that a new paradigm is likely to attract opponents: it is proposed while the supporting evidence is still ambiguous. Most experts will then oppose it for the right reasons (the evidence ain't convincing) rather than the wrong ones (close-minded adherence to the old world view)—despite anything Kuhn, the press or the beleaguered scientists and inventors might say to the contrary.

The history of science and technology is actually rife with new paradigms that were so compelling they were accepted with little opposition. The emergence of molecular biology is one example, as the British biologist Lewis Wolpert has noted. "The evidence from the structure of DNA and other key discoveries was so persuasive that almost everyone—certainly the young—got caught up in the excitement of what is clearly a new age for biology," he writes. Or take Claude Shannon's theory of information, backbone of today's digital revolution. When Shannon published his theory in 1948, it was so compelling, recounts author M. Mitchell Waldrop *(see "Claude Shannon: Reluctant Father of the Digital Age,"* TR *July/August 2001)*, that it "exploded with the force of a bomb. Around MIT, the reaction was, 'Brilliant! Why didn't I think of that?'" Simply put, the excitement of a legitimate new discovery is a stronger motivating force in science than petty self-interest.

In this era when a potential new paradigm can be worth the wealth of OPEC, when an entire field of science or technology can emerge virtually overnight on the basis of a single scientific publication, the challenge lies in differentiating the valid paradigmatic breakthrough from the compelling fantasy. Both, after all, will garner supporters and copious press, because both promise wondrous things. The press, however, will be worthless at rendering sober judgment; reporters will back the new-paradigm angle because that's the better story. They will allude to the abundance of believers as proof that the new paradigm is correct. If there happens to be an abundance of skeptics, the reporters will cite them as evidence that Kuhn was right and that the experts are petty and lacking in vision, rather than as evidence that the new new thing is worthy of skepticism.

The reality is that vigorous skepticism aimed at a potential new paradigm means one of two things and usually both: first, that the spectacular breakthrough or the wondrous paradigm is indeed too good to be true, and second, that the reasons to be skeptical are very good ones. If the evidence supporting the new paradigm reaches a high enough pitch, then the skepticism will fade. (Although, as the new economy suggests, even if it does, we should keep our heads.) The longer that skepticism lasts, the more likely it is that the new paradigm is delusional and will eventually evaporate in the harsh light of reality. Should you buy into it despite the skepticism, then, as one of my old engineering professors liked to say, you pays your money and you takes your chances.

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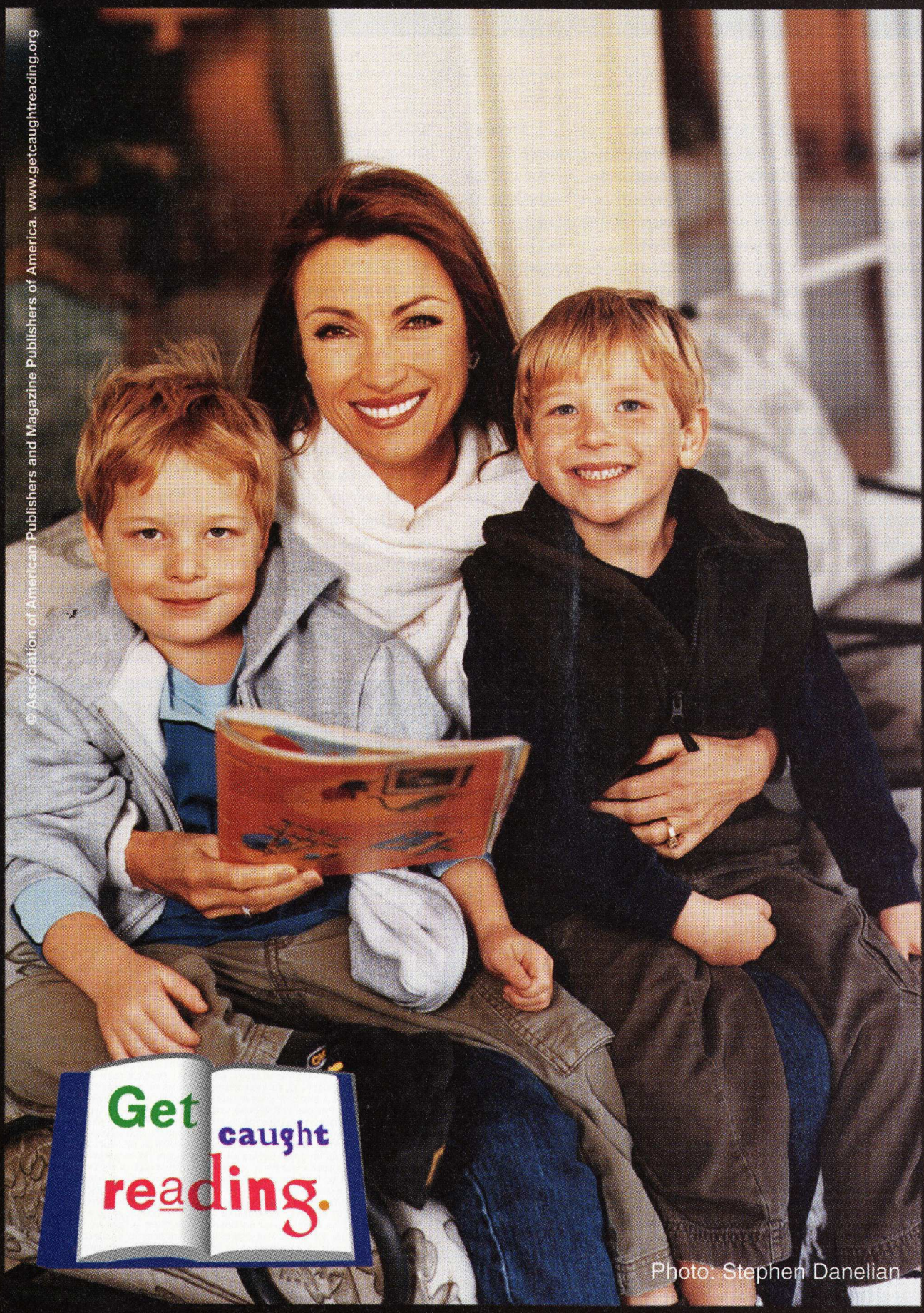

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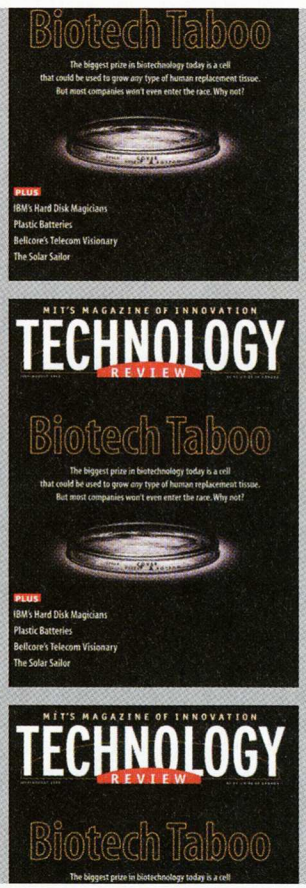

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COURTESY OF CORNING GLASS MUSEUM

DRAWING OPTICAL FIBERS

A college junior shed new light on a century-old problem

Today the optical fibers that carry phone calls and Internet traffic (as well as images of patients' interiors through endoscopes) seem to have been around forever. Indeed, the basic idea of using glass rods to guide light dates back at least to the 1840s. But the problem of making a glass surface smooth enough to transmit light took more than a century to solve. Ultimately, it was an undergraduate's weekend gamble that paid off.

Fibers start out smooth, but when they're bundled together to transmit images or other data, their surfaces scratch each other, letting light ooze out. Researchers thought that a cladding, or insulation, made from a material less optically dense than glass would reflect the light back inside the fibers. But trials with materials from margarine to beeswax all disappointed.

Then Larry Curtiss had a brainstorm. In 1956, Curtiss was a University of Michigan junior, working to build a flexible fiber-optic endoscope to examine the stomach. When bare fibers didn't work, he wondered if wrapping them in another kind of glass might. He knew that, since the glass tubing used in chemistry labs was less optically dense than the rods he was testing, it should trap light inside the fiber's core. His idea was to slip the core rod into such tubing, melt them together and then draw out glass-clad fibers from the hot material. But several physics professors told him the glass coating would crack, making it useless. They suggested he stick to plastic instead.

On December 8, 1956, the professors left for a conference, so Curtiss decided to try the glass tubing. He melted it around a rod and walked away from the furnace pulling out a thin glass fiber. "I was 40 feet down the hall, and I could still see the glow of the fiber," Curtiss recalls. The fiber was transmitting light all the way down the hall—much farther than necessary for an endoscope. Curtiss collected his early fibers by winding them around oatmeal boxes like the one above. Within 10 weeks gastroenterologist Basil Hirschowitz had examined a patient's ulcers through an endoscope made from the new fibers.

Fiber-optic medical imaging was off and running. In the early 1960s, communications researchers started using glass-clad fibers to transmit voice data. But while Curtiss's essential idea held true, the fibers used in communications had to be made from much purer glass using different technology—so the patent he received didn't extend to that field. Based in Concord, MA, Curtiss still works as a consultant in the optical-fiber field.

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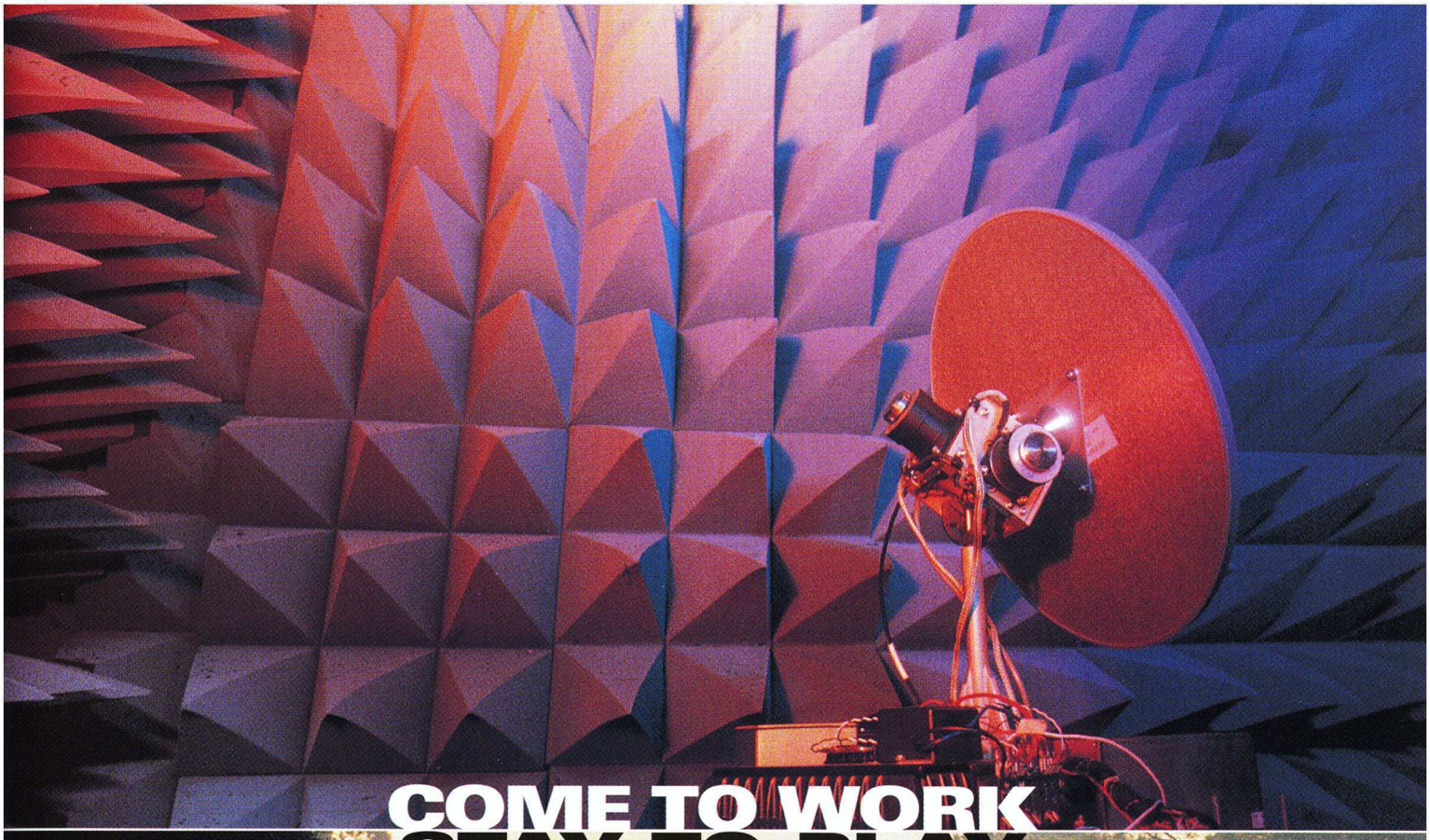

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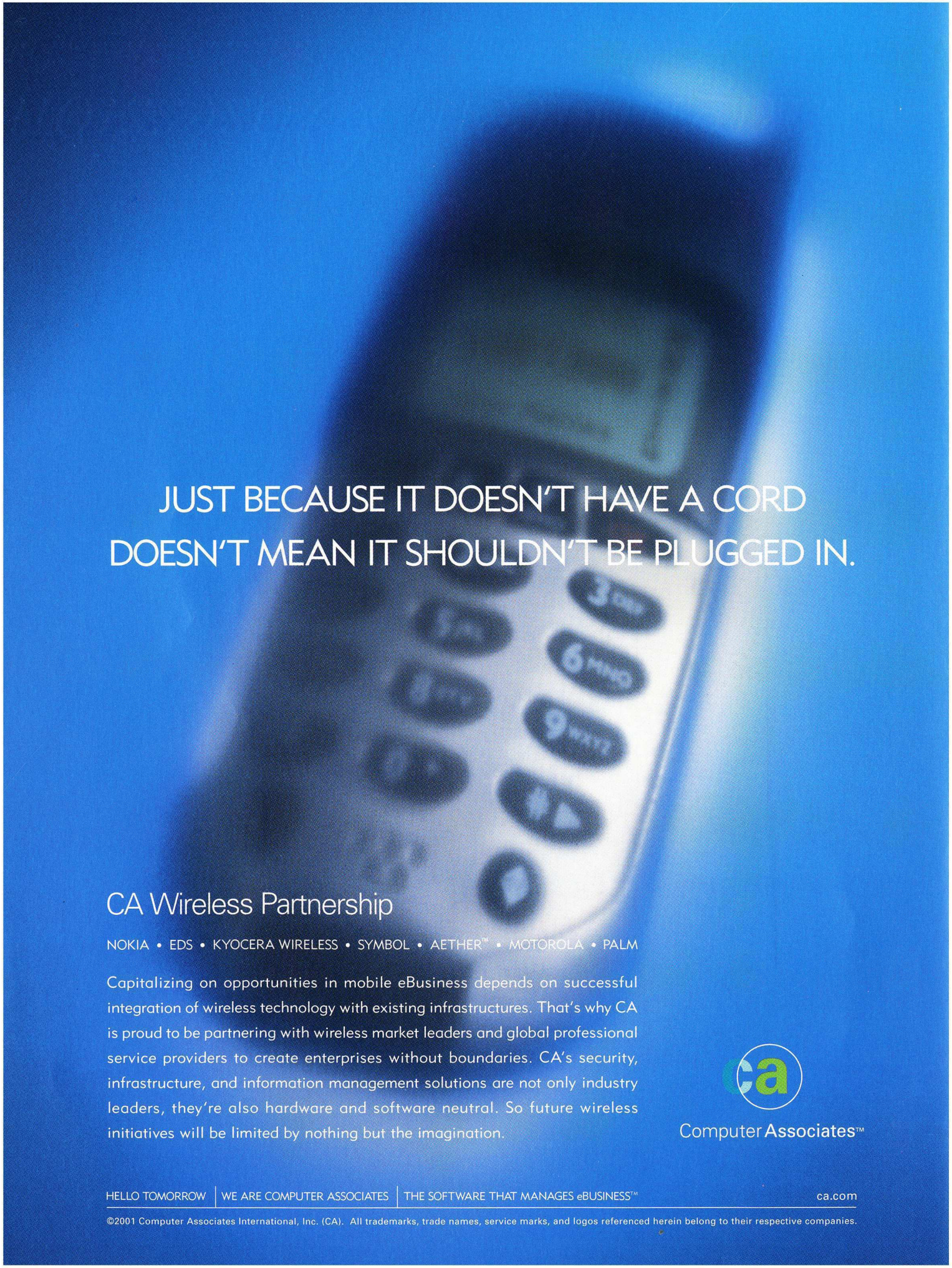
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